ASD-TDR-63-679
PART III

PRESSURE AND HEAT TRANSFER MEASUREMENTS FOR HYPERSONIC FLOWS OVER EXPANSION CORNERS AND AHEAD OF RAMPS

PART III: MACH 8 PRESSURE DATA FOR FLOWS AHEAD OF RAMPS

Part of an Investigation of Hypersonic Flow Separation and Control Characteristics

DEPARTMENT OF AERONAUTICS
U. S. Naval Postgraduate School
Monterey, California

TECHNICAL DOCUMENTARY REPORT No. ASD-TDR-63-679, PART III

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FLIGHT CONTROL DIVISION
AIR FORCE FLIGHT DYNAMICS LABORATORY
AERONAUTICAL SYSTEMS DIVISION
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FOREWORD

This entire report, written in four parts under separate covers, presents the results of a portion of the experimental program for the investigation of hypersonic flow separation and control characteristics being conducted by the Research Department of Grumman Aircraft Engineering Corporation, Bethpage, New York. Mr. Donald E. Hoak of the Flight Control Laboratory, Aeronautical Systems Division, located at Wright-Patterson Air Force Base, Ohio, is the Air Force Project Engineer for the program, which is being supported primarily under Contract AF33(616)-8130, Air Force Task 821902.

The author wishes to express his appreciation to the staff of the von Karman Facility for their helpfulness in conducting the tests; their gracious assistance in preparing these reports; and particularly to Messrs. Schueler, Baer and Burchfield for providing the machine plotted graphs of the experimental data included in this report. Ozalid reproducible copies of the tabulated data are available on loan from the Flight Control Laboratory.

The parts which constitute a complete report for this segment of the over-all program are:

Part I: Mach 5 and 8 Data for Expansion Corner Flows

Part II: Mach 5 Pressure Data for Flows Ahead of Ramps

Part III: Mach 8 Pressure Data for Flows Ahead of Ramps

Part IV: Mach 8 Heat Transfer Data for Flows Ahead of Ramps

ABSTRACT

Pressure and heat transfer data were obtained for hypersonic flows over 40-degree expansion corners and ahead of ramps. Full and partial span ramps, having wedge angles up to 90 degrees, were tested at two locations on a sharp leading edge flat plate, with and without end plates. Pressure data were obtained for $M_\infty = 5$ for model length Reynolds numbers between 1.1 and 6.6 million. Both pressure and heat transfer data were obtained for $M_\infty = 8$ for Reynolds numbers between 1.1 and 3.3 million.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Charles B. Westbrook

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Chief, Aerospace Mechanics Branch
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LIST OF ILLUSTRATIONS

*See Table II, page 6, for figure numbers corresponding to particular test conditions.

LIST OF SYMBOLS

C_p	pressure coefficient, $C_p \equiv (p - p_\infty)/q_\infty$
M_∞	free stream Mach number
p	pressure (psia)
p_o	stagnation pressure (psia)
p_∞	free stream static pressure (psia)
q_∞	free stream dynamic pressure (psia)
Re_∞/ft	Reynolds number per foot, $Re_\infty/ft \equiv \rho_\infty U_\infty/\mu_\infty$
T_o	stagnation temperature (°R)
T_∞	free stream static temperature (°R)
U_∞	free stream velocity (ft/sec)
X'	nondimensional streamwise distance downstream of the leading edge, measured on the surface
Y'	nondimensional spanwise distance measured outboard from the model centerline
α	angle of attack of model (degrees)
μ_∞	viscosity of air in the free stream (slugs/ft sec)
ρ_∞	density of air in the free stream (slugs/ft^3)

INTRODUCTION

The experimental data generated for an investigation of hypersonic flow separation and aerodynamic control characteristics are to be presented in a series of reports, of which this is one. Pressure, heat transfer, and force data are to be obtained for hypersonic flows over "basic geometries," such as a wedge mounted on a flat plate, and for "typical" hypersonic flight configurations with aerodynamic control surfaces. The experimental portion of the program requires a total of 11 models (see Fig. 1, page 8); 8 for tests in the von Karman Facility of the Arnold Engineering Development Center and 3 for tests in the Grumman Hypersonic Shock Tunnel (Refs. 1 and 2). The data obtained from AEDC tests of one of the models are given in this four-volume report (see Foreword).

This report (Part III) presents the pressure data obtained in the AEDC 50-inch Mach 8 Tunnel on a flat plate model having three, remotely controlled, flaps. The heat transfer data, obtained in the same tunnel, are presented in Part IV of this report. The same model was tested in the AEDC 40-inch Supersonic Tunnel to obtain pressure distributions for $M_\infty = 5$. Geometrically similar models, one with internal cooling and the other with limited pressure and heat transfer instrumentation, were tested in the AEDC 50-inch Mach 8 Tunnel and in the Grumman Hypersonic Shock Tunnel (see Fig. 1).

MODEL

The model has a nominally sharp leading edge (35° included angle) and has a 12-inch square planform. A photograph of the model, with end plates attached, is shown in Fig. 2. The removable end plates are slightly toed in to account for the boundary layer growth along the inner walls of the end plates. There are three remotely controlled flaps on the model which are individually actuated by drive screws run by 28 volt dc electric motors. The three motors and drive screws are located in the water cooled housing immediately behind the model (see Fig. 2), and are connected to the flap bell cranks by push-pull rods.

The geometry of the flaps is indicated in Fig. 3. The forward flap has a 1-inch chord, is deflectable through 90 degrees, and has its hinge line located three inches downstream of the sharp leading edge of the model. The aft flap has a 3-inch chord, is deflectable

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through 45 degrees, and has its hinge line 9 inches downstream of the leading edge. The center portion of the aft flap, having a span of 4 inches, can be deflected separately.

The chord to hinge-line station ratio of the forward and aft flaps are the same, providing data on Reynolds number and leading edge effects. When deflected 90 degrees, the forward flap serves as a forward facing step. Another function of this flap is to create separated flows which reattach on the flat plate downstream of it. The aft flap serves to form forward facing ramps of various angles up to 45 degrees. Span and tip effects are obtained by using the center portion of the aft flap and the end plates.

Pressure tap locations, as well as the locations of the thermocouples used for Part IV of this series, are shown in Fig. 3.

TEST CONDITIONS

The pressure data presented herein were obtained from tests in the AEDC 50-inch Mach 8 Tunnel (Ref. 3). The model was pitched from 30 degrees nose down to 15 degrees nose up for various flap settings and for free stream Reynolds numbers per foot of 1.1, 2.2 and 3.3 million. The tunnel conditions corresponding to the different Reynolds numbers are shown in Table I; the model configurations, flap settings, and test conditions are shown in Table II. Flap deflections were set using Leeds and Northrup indicator readings of potentiometers connected to each drive screw in the water cooled housing. The potentiometer readings for the desired flap settings were calibrated while the model was cold (using hand held templates); the flap settings were checked frequently while the tunnel was running by using scribe lines and a surveyor's transit. Further, "limit" lamps on the flap control panel lighted when the flaps were at their minimum and maximum deflections.

DATA REDUCTION AND ACCURACY

All pressure data were reduced to standard pressure coefficient form:

$$C_p = \frac{p - p_\infty}{q_\infty} ,$$

where p is the measured pressure; p_∞ is the free stream static pressure; and q_∞ is the free stream dynamic pressure. The inaccuracy in the measured pressure varies from ±0.003 psia for pressures below 0.40 psia, to ±0.026 psia for pressures greater than 15 psia. Pressure coefficient uncertainties vary, for example, from 0.004 for $C_p < 0.3$ and $Re_\infty/ft = 1.1$ million, to 0.013 for $C_p = 2.0$ and $Re_\infty/ft = 3.3$ million. At the higher pressure coefficients, the greatest part of the inaccuracy is due to the deviations in the Mach 8 free stream dynamic pressure (Ref. 4).

The automatic plotting machines, used in presenting the data herein, introduce another source of possible error. The discrepancy in the plotted pressure coefficients due to this machine error should not exceed ±0.01. Nevertheless, there is always the rare possibility that a point will be completely misplotted. Each graph has been inspected and questionable points checked with the tabulated pressure coefficients.

Finally, the remotely controlled flap settings were estimated to be accurate to well within half a degree.

RESULTS

Table II summarizes the Mach 8 pressure data obtained on the upper portion of the model and indicates the corresponding figure numbers where the sets of data are presented. The AEDC group number is presented in the last column. This number indicates the order in which the data were obtained and is to be used when referring to the tabulated data.

Streamwise and spanwise plots of the pressure coefficients are presented in Figs. 4 through 64. The first page of each figure presents streamwise plots of the pressure coefficients at two semispan stations, one essentially along the centerline, at $Y' = 0.03$, and the other outboard, at $Y' = 0.34$. Six spanwise plots of the data are presented on the second page of each figure: one upstream of the forward flap, at $X' = 0.18$, one on the forward flap, at $X' = 0.29$, two upstream of the aft flaps, at $X' = 0.59$ and 0.68, and two on the aft flaps, at $X' = 0.83$ and 0.92.

Although the accuracy of the plotted data should suffice for engineering purposes, ozalid reproducible copies of the tabulated data are available on loan (see Foreword). The plotted data may be read accurately using standard 20/inch grid, tracing graph paper overlays.

REFERENCES

1. Kaufman, L.G. II, Oman, R.A., Hartofilis, S.A., Meckler, L.H., Evans, W.J., and Weiss, D., A Review of Hypersonic Flow Separation and Control Characteristics, ASD-TDR-62-168, March 1962.

2. Evans, W.J., and Kaufman, L.G. II, Pretest Report on Hypersonic Flow Separation and Control Models for AEDC Tunnels A, B, Hotshot 2 and Grumman Hypersonic Shock Tunnel, Grumman Research Department Memorandum RM-209, July 1962.

3. Arnold Center, Test Facilities Handbook, Arnold Air Force Station, January 1961.

4. Kaufman, L.G. II and Meckler, L.H., Pressure and Heat Transfer Measurements at Mach 5 and 8 for a Fin-Flat Plate Model, ASD-TDR-63-235, February 1963.

5. Hartofilis, S.A., Pressure Measurements at Mach 19 for a Winged Re-entry Configuration, ASD-TDR-63-319, March 1963.

6. Meckler, L.H., Static Aerodynamic Characteristics at Mach 5 and 8 for an Aerodynamically Controllable Winged Re-entry Configuration, to be published as an ASD Technical Documentary Report.

7. Kaufman, L.G. II, Pressure and Heat Transfer Measurements for Hypersonic Flows Over a Blunt Pyramidal Configuration with Aerodynamic Controls, to be published as an ASD Technical Documentary Report.

TABLE I

TUNNEL CONDITIONS

$Re_{\infty}/10^6$ ft	1.1	2.2	3.3
M_{∞}	8.04	8.08	8.09
p_{∞} (psia)	0.025	0.049	0.074
q_{∞} (psia)	1.14	2.22	3.38
p_o (psia)	254	510	775
T_o (°R)	1,340	1,360	1,340

TABLE II

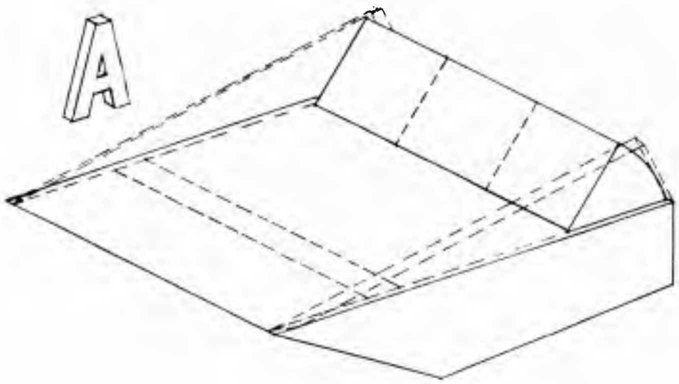
TEST CONDITIONS

End Plates	Flap Settings (deg) For-ward	Aft Center	Aft Full Span	$\frac{Re_\infty}{10^6 \text{ ft}}$	α (deg)	C_p Plots Fig. Nos.	AEDC Group Nos.
OFF				3.3	-30	4	62
OFF			45*	1.1	-15	5	61
OFF				3.3	-15	6	54
			10			7	55
			20			8	56
			30			9	58
OFF			45	3.3	-15	10	59
OFF				3.3	-5	11	53
OFF			30	3.3	-5	12	57
ON				1.1	0	13	15
ON				1.1		14	18**
OFF				2.2		15	49
OFF				3.3		16	25
ON				3.3		17	1
OFF	10			3.3		18	37
ON			10	1.1		19	19
OFF			10	3.3		20	29
ON			10	3.3		21	4
OFF	15			3.3		22	38
ON	15			3.3		23	12
OFF	20			3.3		24	39
ON			20	1.1		25	20
OFF			20	3.3		26	30
ON			20	3.3		27	5
ON	30			1.1		28	23
OFF	30			3.3		29	40
ON	30			3.3		30	13
OFF		30		3.3		31	45
ON			30	1.1		32	21
OFF			30	2.2		33	51
OFF			30	3.3		34	34
ON			30	3.3		35	6
OFF			45*	1.1		36	60
ON			45	1.1		37	22
OFF			45	3.3		38	36
OFF			45	3.3		39	47**
ON			45	3.3		40	11
OFF	90			3.3		41	43
ON	90			3.3	0	42	14

End Plates	Flap Settings (deg) For-ward	Aft Center	Aft Full Span	$\frac{Re_\infty}{10^6 \text{ ft}}$	α (deg)	C_p Plots Fig. Nos.	AEDC Group Nos.
ON				1.1	+5	43	16
OFF				2.2		44	50
OFF				3.3		45	26
ON				3.3		46	2
OFF	30			3.3		47	41
OFF			30	2.2		48	52
OFF			30	3.3		49	33
OFF			30	3.3		50	48**
ON			30	3.3		51	7
ON			45	3.3	+5	52	10
ON				1.1	+15	53	17
OFF				3.3		54	27
ON				3.3		55	3
OFF			10	3.3		56	28
OFF			20	3.3		57	31
OFF	30			3.3		58	42
ON			30	1.1		59	24
OFF			30	3.3		60	32
ON			30	3.3		61	8
OFF			45	3.3		62	46
ON			45	3.3		63	9
OFF	90			3.3	+15	64	44

*Due to a flap malfunction, the outboard port portion of the aft flap was misaligned (at about 30 degrees) during AEDC Group Nos. 60 and 61 (no pressure taps are in this portion of the flap).

**Repeat runs.

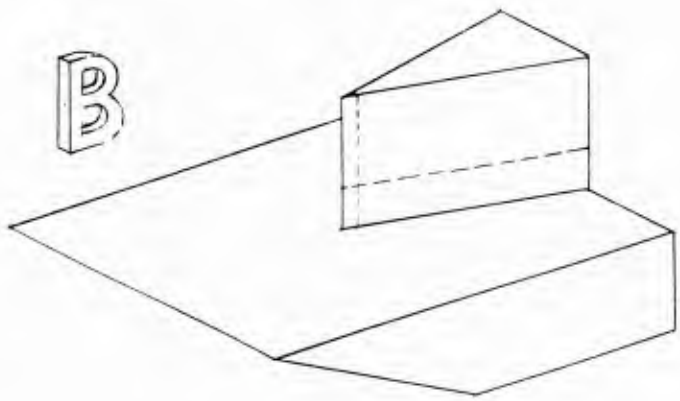


Separated Flows ahead of a Ramp
Fore and aft flaps, end plates
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results herein.

2) Controlled wall temperature, pressure, AEDC Tunnel B, M = 8, results not available yet.

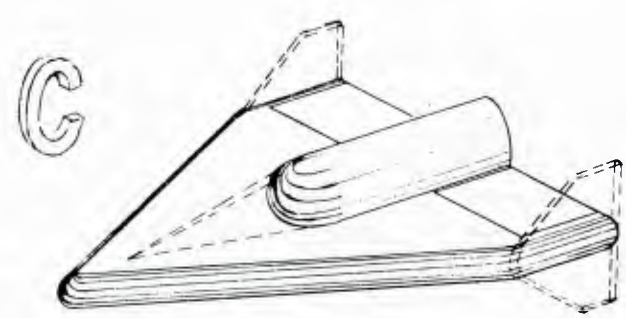
3) Pressure and heat transfer, Grumman Shock Tunnel, M ≈ 13 & 19, results not available yet.



Wedge - Plate Interaction
Small and large fins with sharp and blunt leading edges
2 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results in Ref. 4.

2) Pressure and heat transfer, Grumman Shock Tunnel, M ≈ 13 & 19, results not available yet.

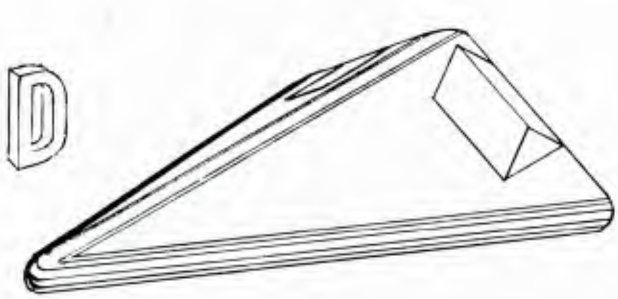


Clipped Delta, Blunt L.E.
Center body, T.E. flaps, drooped nose, spoiler, tip fins
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results not available yet.

2) Pressure, AEDC Hotshot 2, M ≈ 19, results in Ref. 5.

3) Six component force, AEDC Tunnels A & B, M = 5 & 8, results in Ref. 6.



Delta, Blunt L.E., Dihedral
T.E. flaps, carard, ventral fin
3 separate models:

1) Pressure and heat transfer, AEDC Tunnels A & B, M = 5 & 8, results in Ref. 7.

2) Pressure and heat transfer, Grumman Shock Tunnel, M ≈ 19, results not available yet.

3) Six component force, AEDC Tunnels A & B, M = 5 & 8, results not available yet.

Fig. 1 General Outline of Models and Remarks for Over-all Program

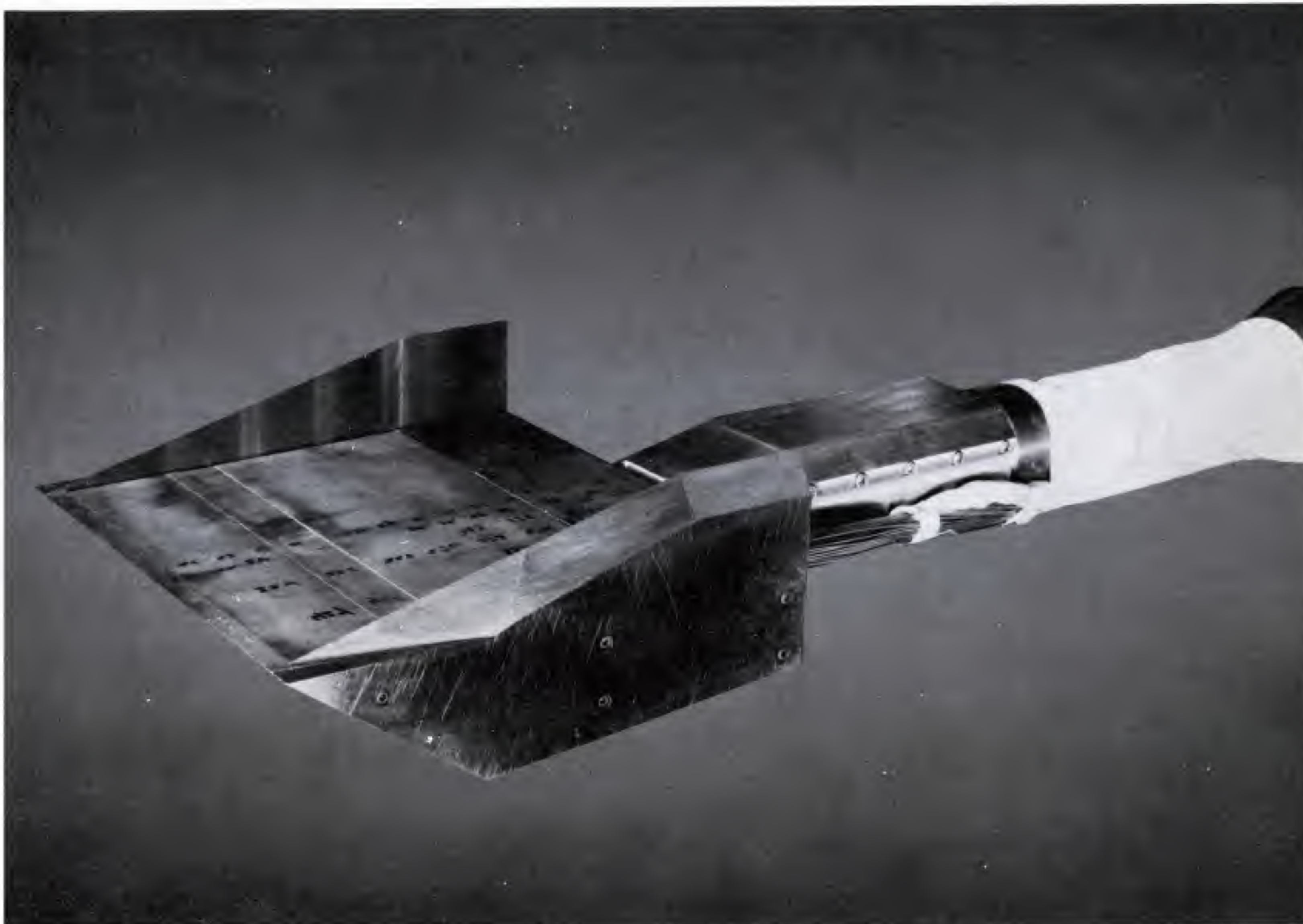


Fig. 2 Photograph of Model with End Plates

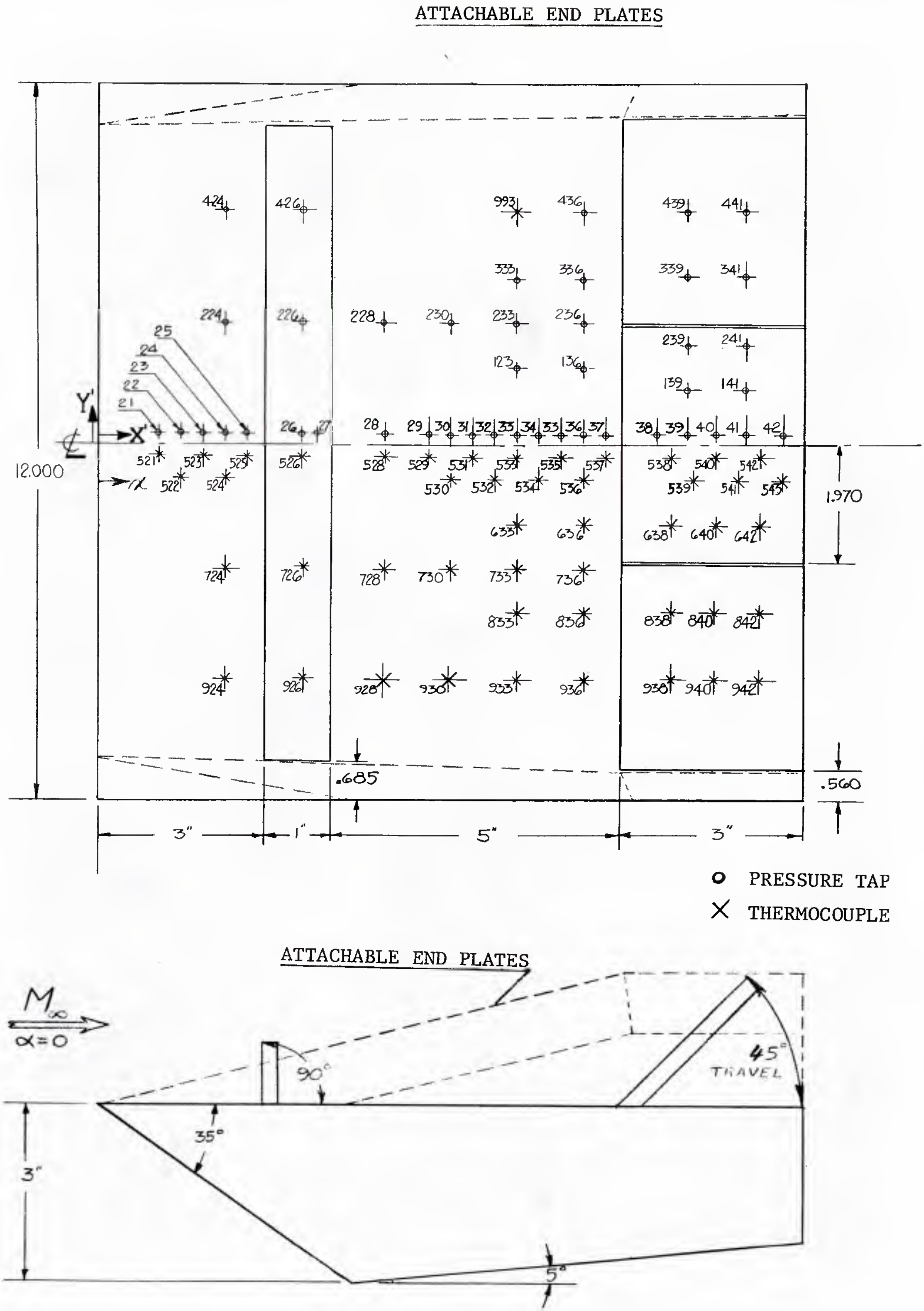
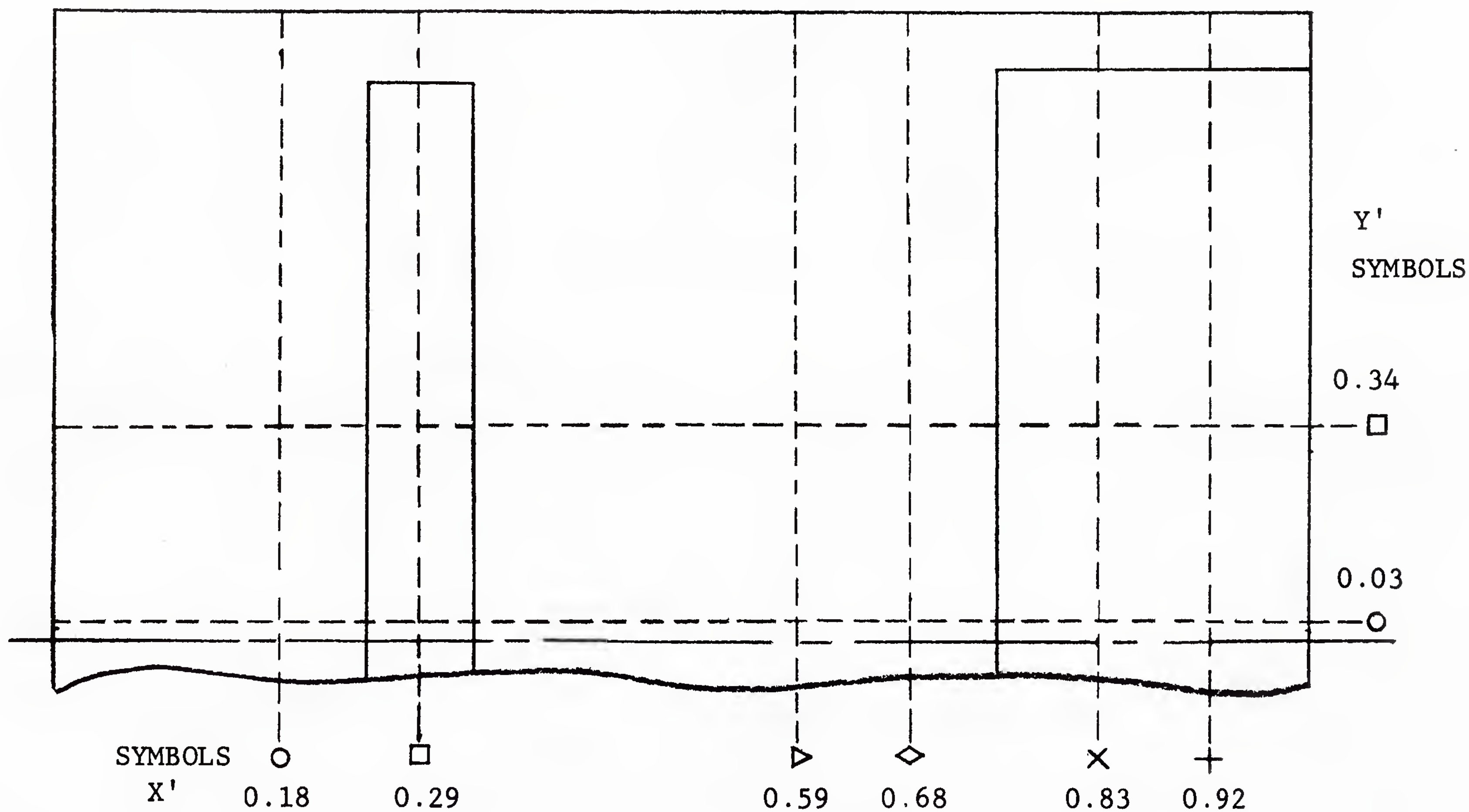


Fig. 3 Instrumentation on Upper Surface of Model



SYMBOLS USED IN FIGURES 4-64

Figure 3 Instrumentation on Upper Surface of Model

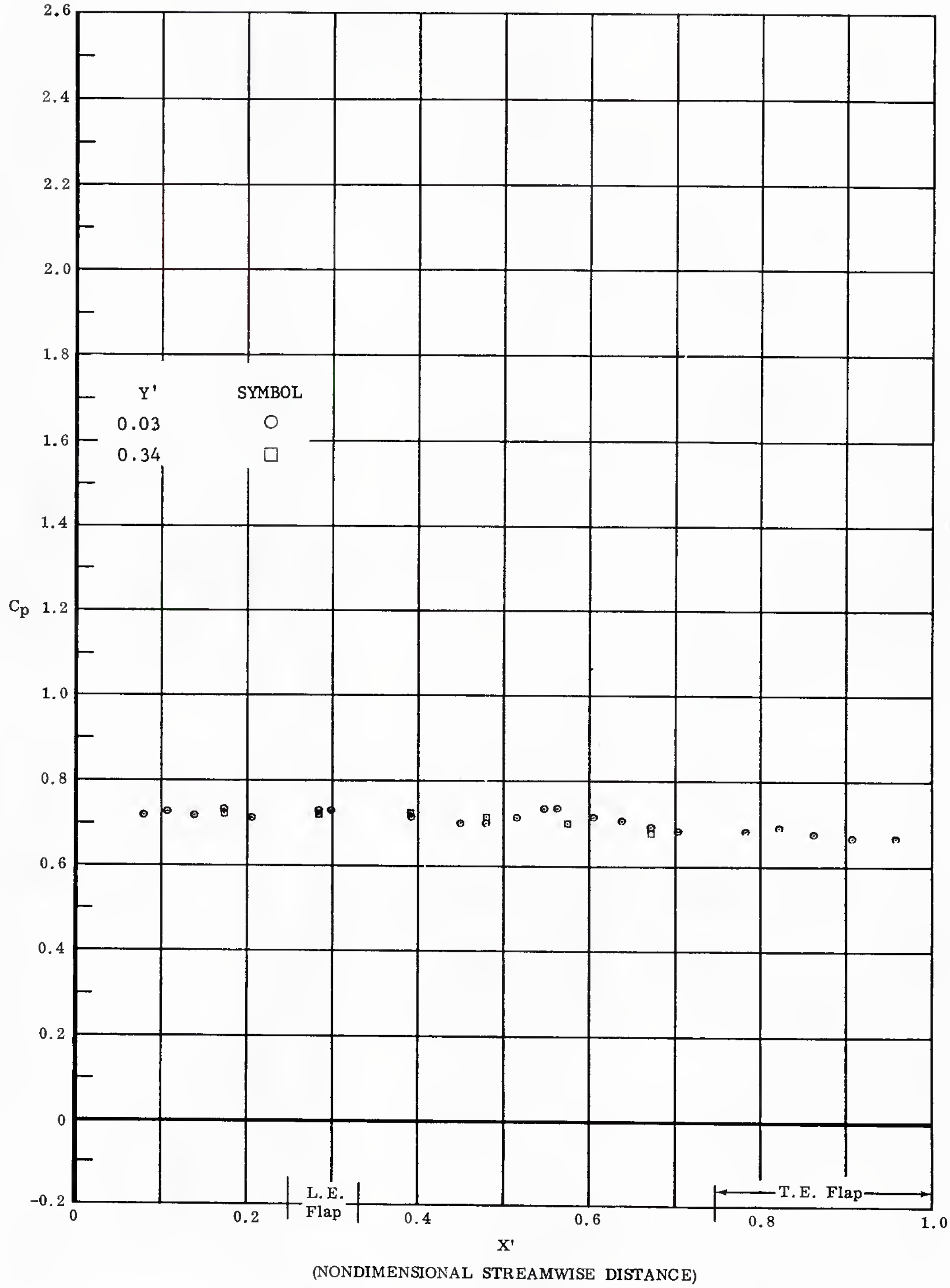


Fig. 4 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -30°$, $Re_\infty/ft = 3,300,000$

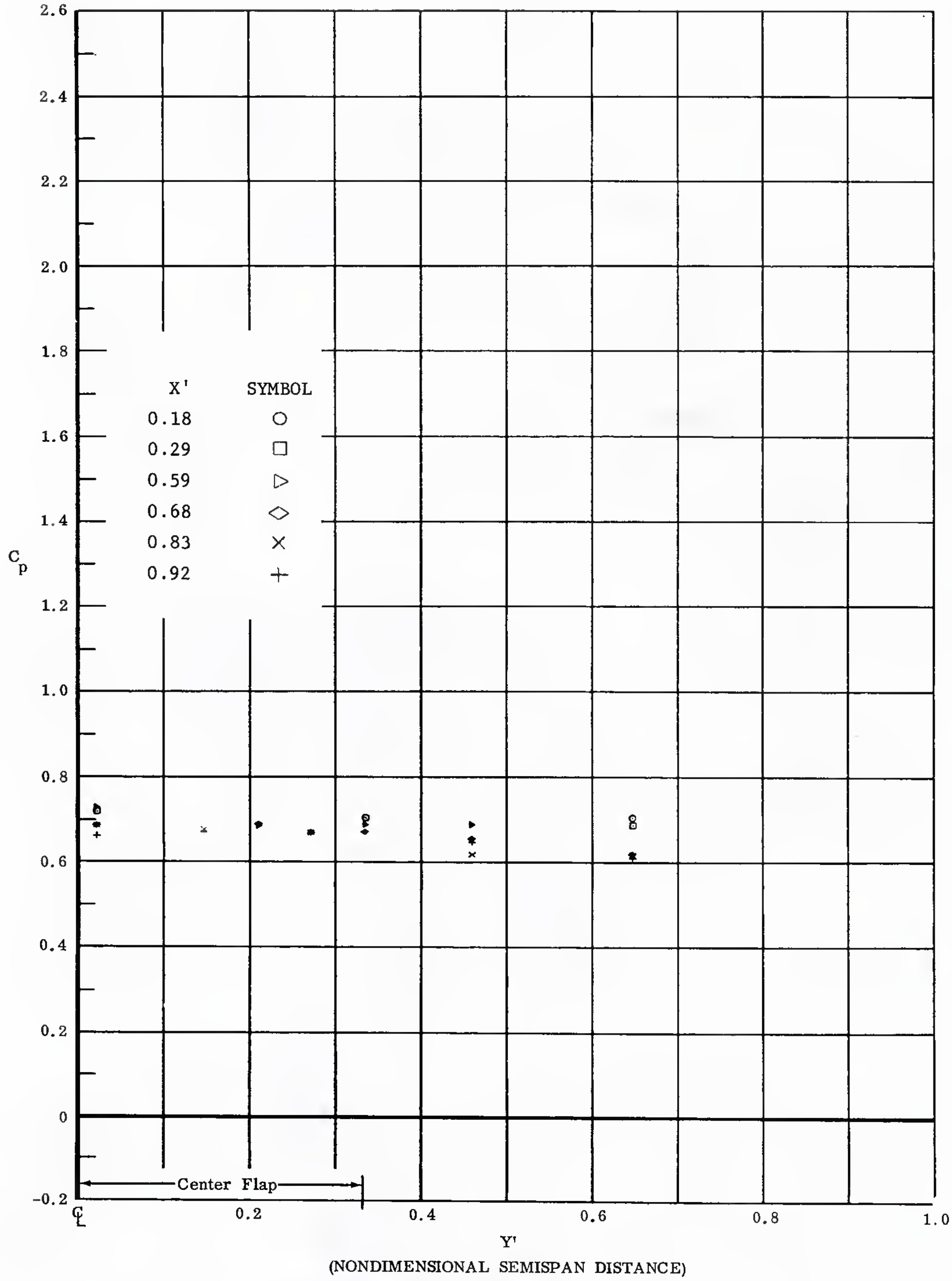


Fig. 4 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -30°$, $Re_{\infty}/ft = 3{,}300{,}000$

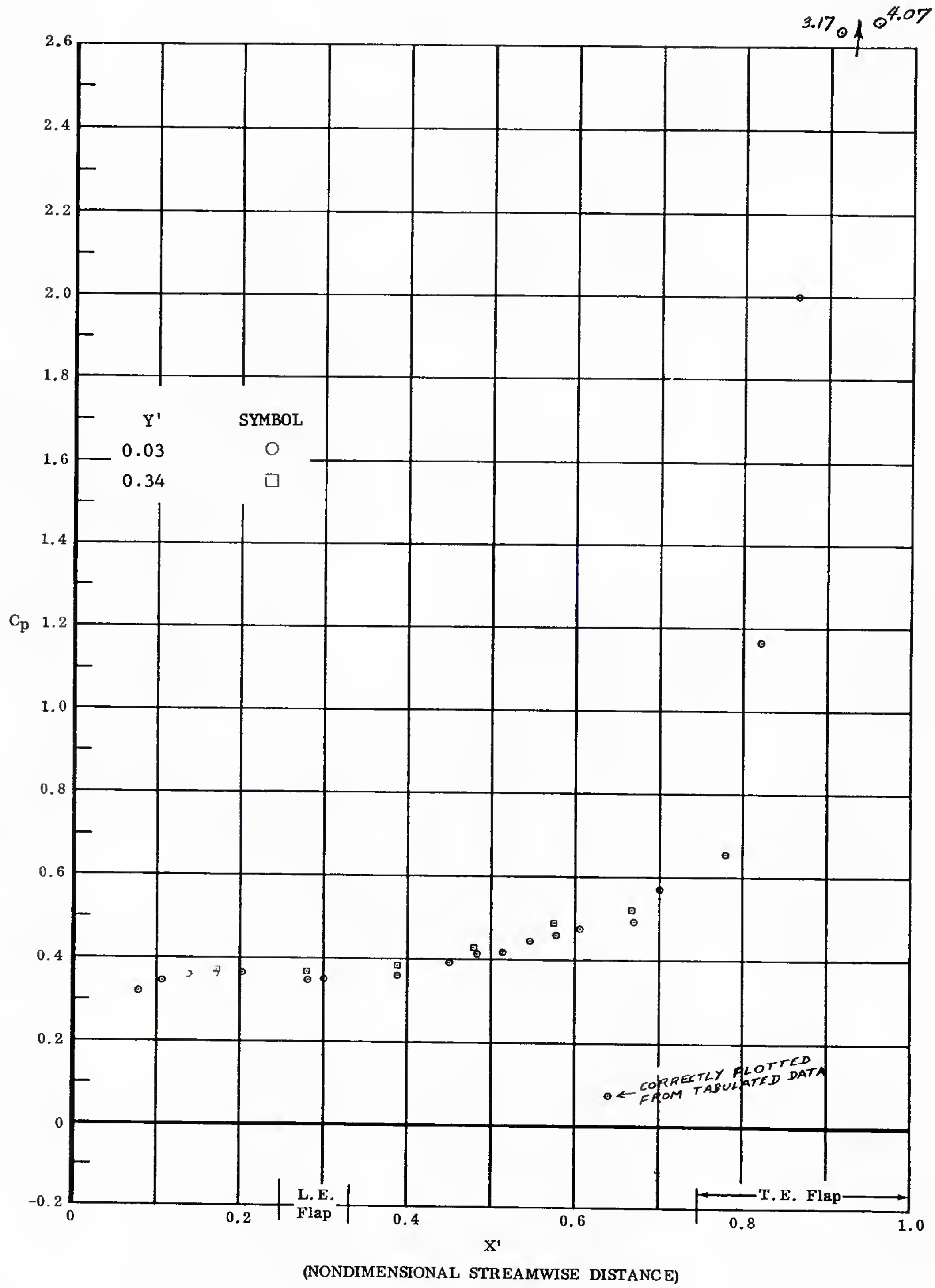


Fig. 5 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°*, $\alpha = -15°$, Re_∞/ft = 1,100,000

*See note in Table II, pages 6 and 7.

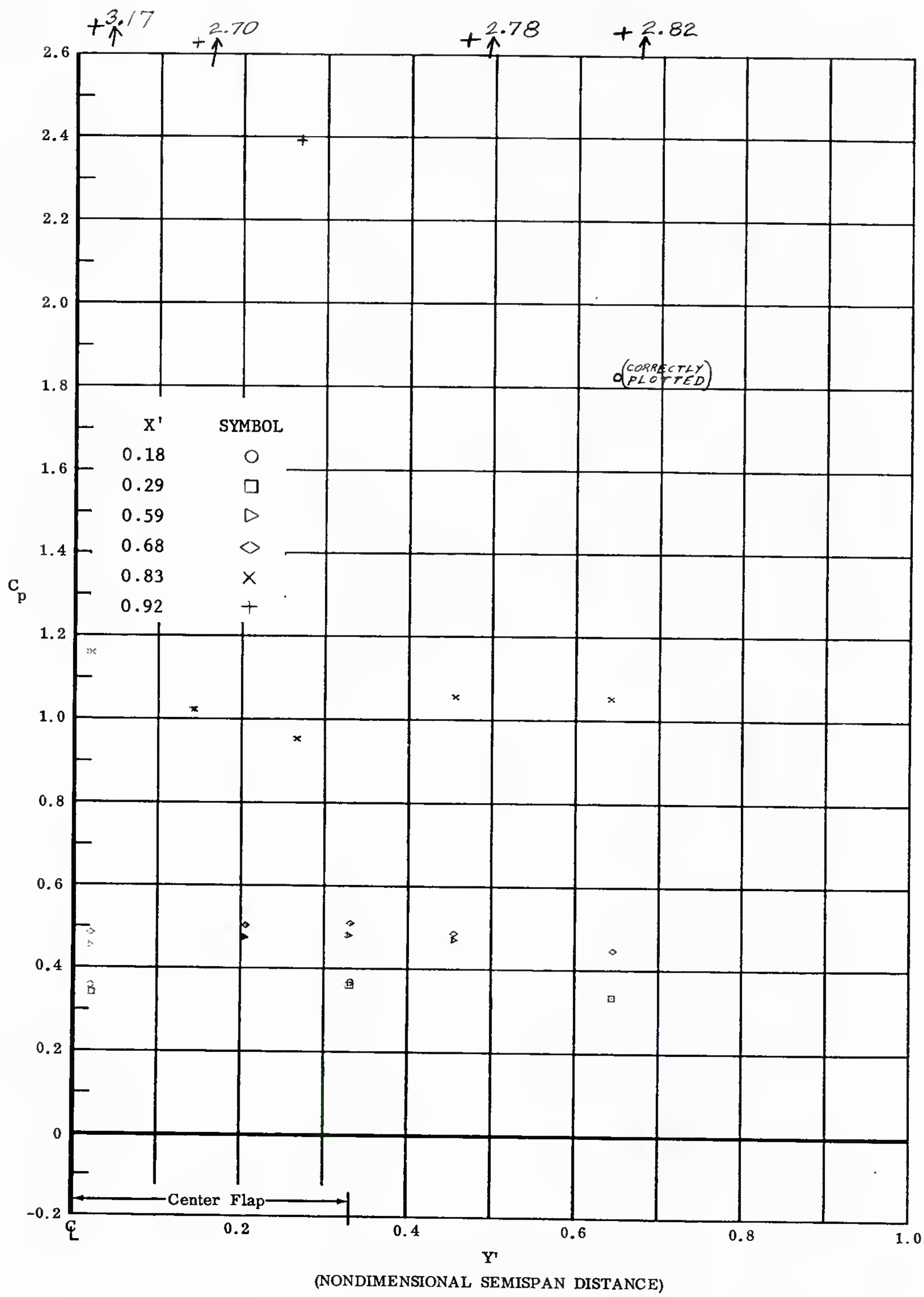


Fig. 5 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°*, $\alpha = -15°$, R_{e_∞}/ft = 1,100,000

*See note in Table II, pages 6 and 7.

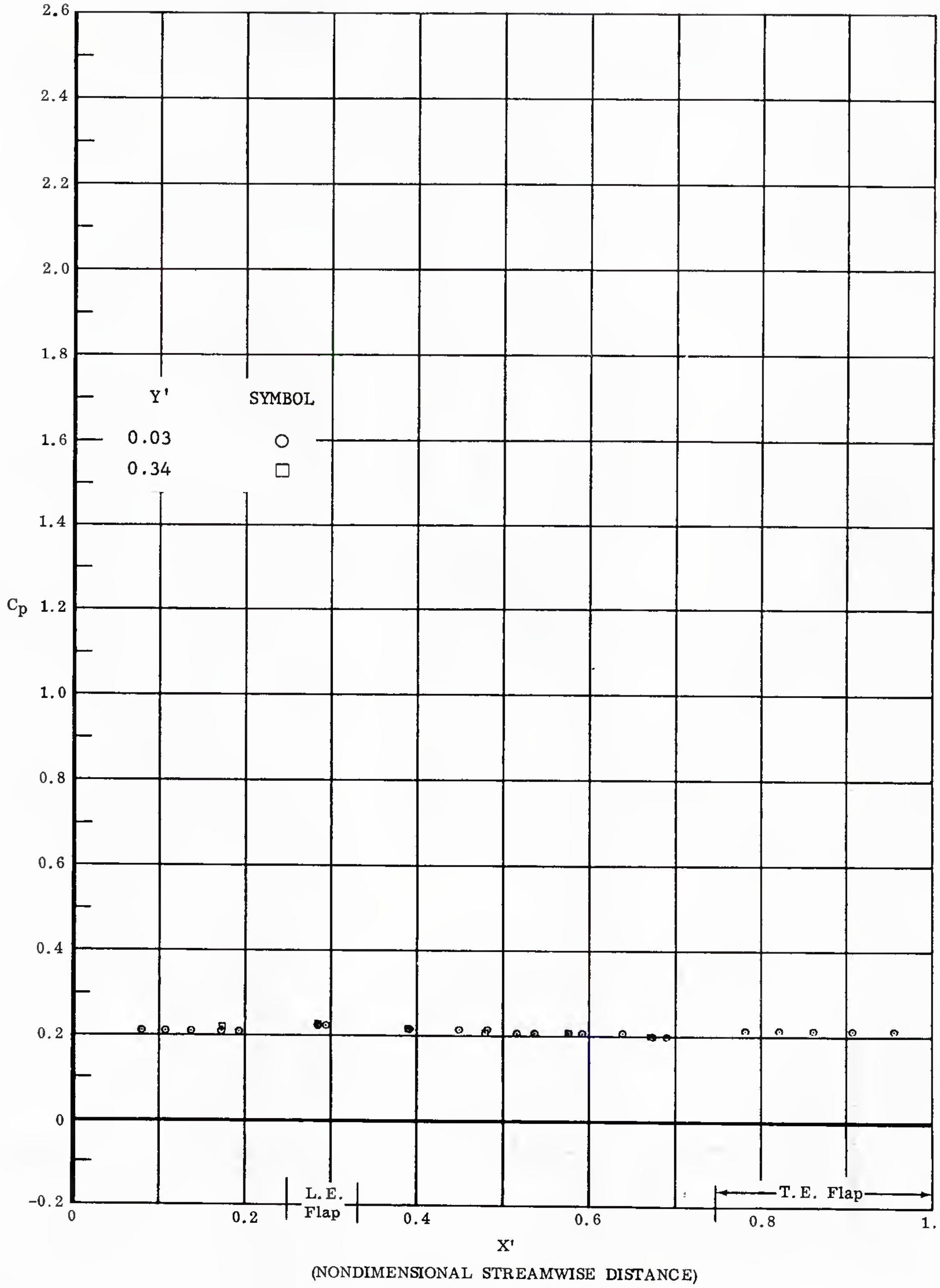


Fig. 6 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -15°$, $Re_\infty/ft = 3,300,000$

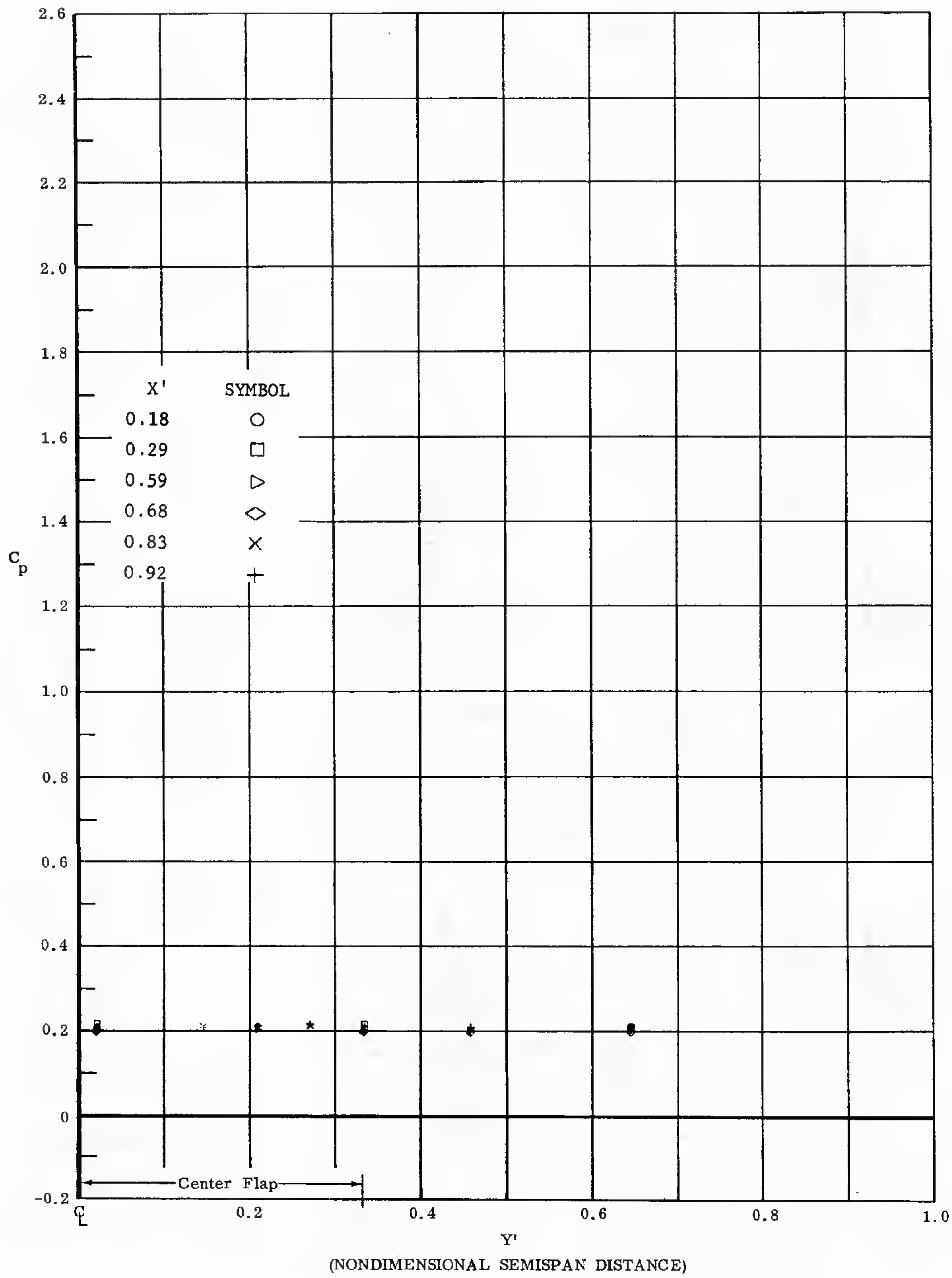


Fig. 6 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -15^\circ$, $Re_\infty/ft = 3{,}300{,}000$

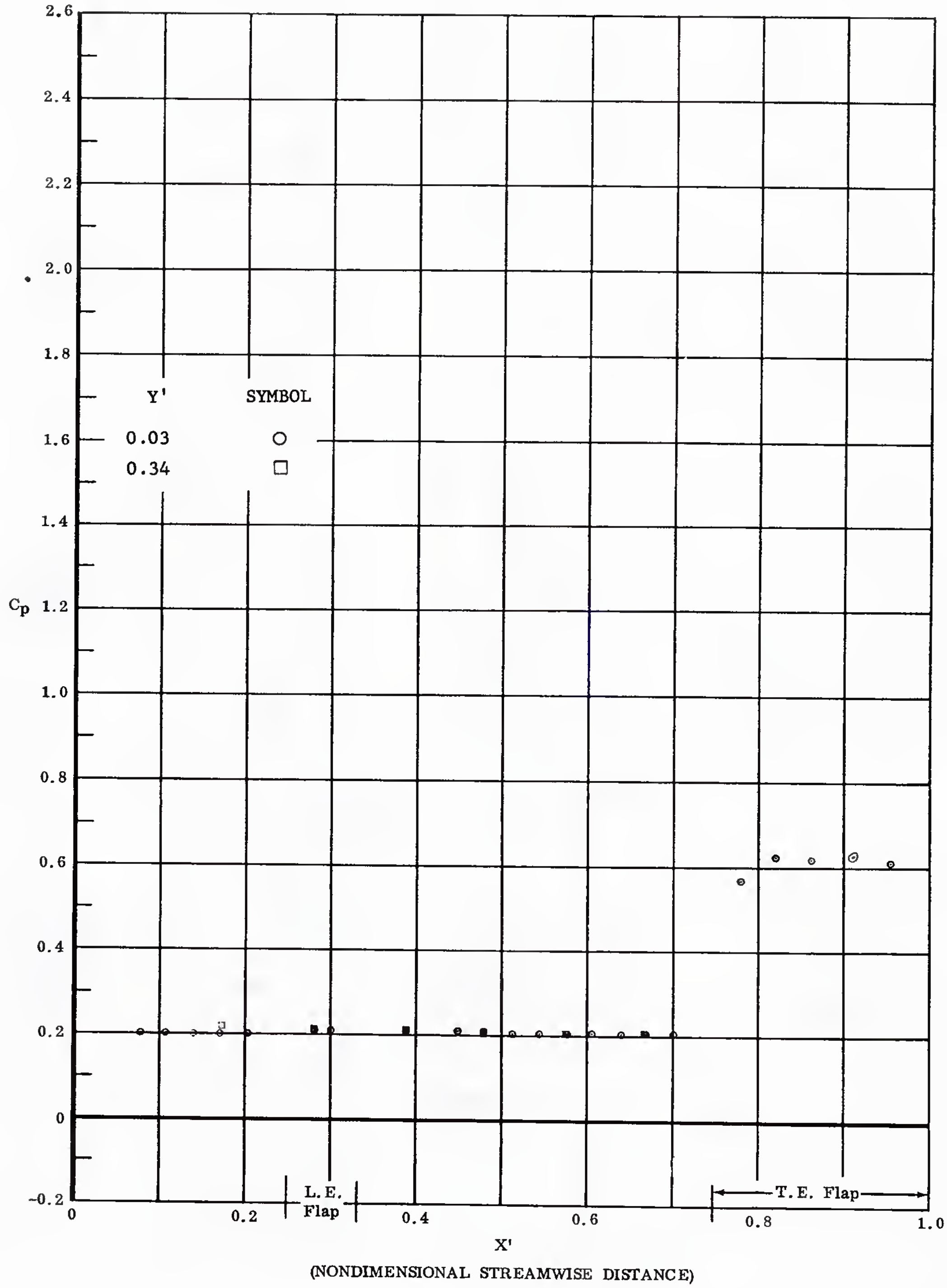


Fig. 7 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 10°, $\alpha = -15°$, Re_{∞}/ft = 3,300,000

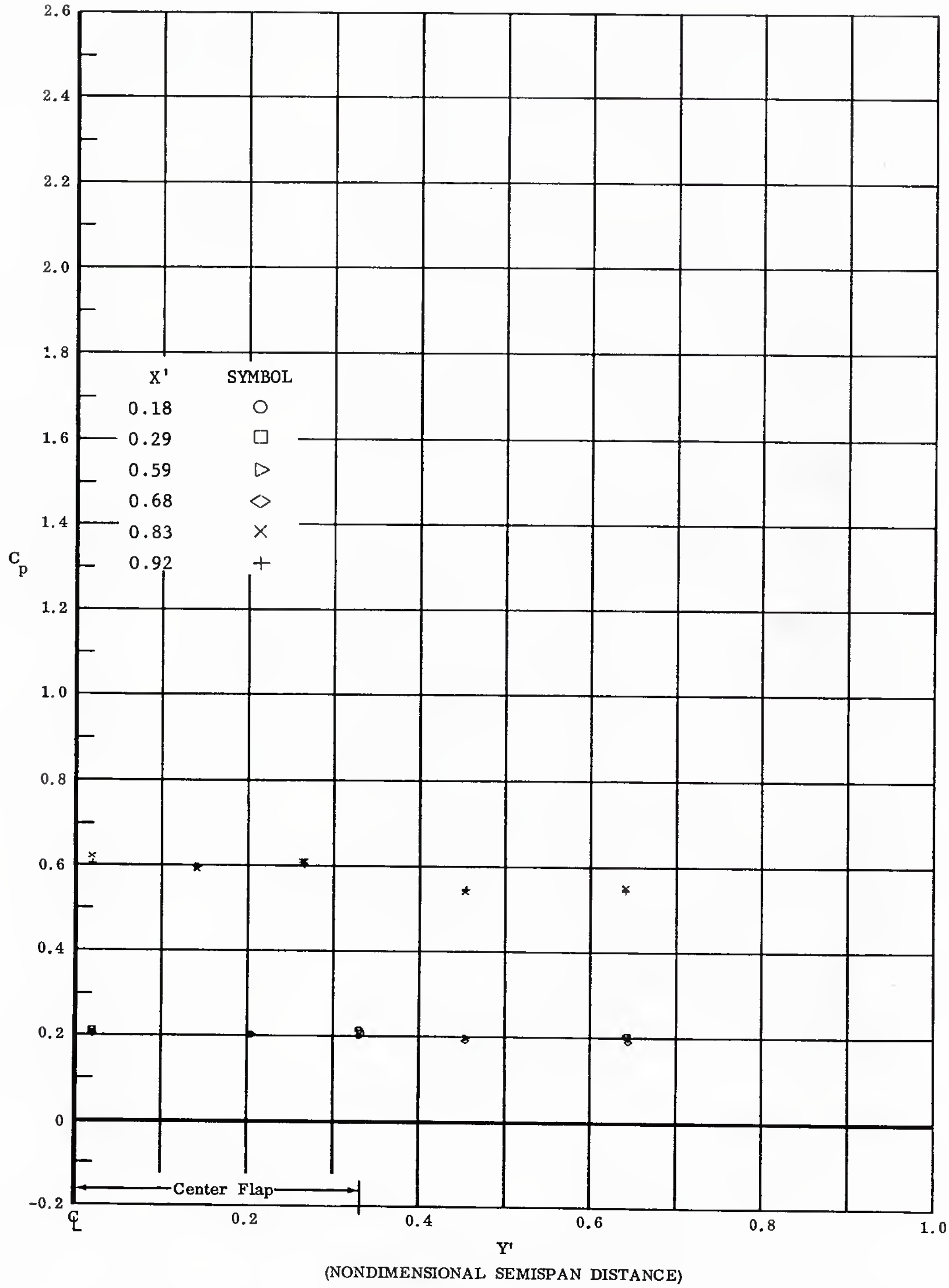


Fig. 7 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 10°, $\alpha = -15°$, $Re_{\infty}/ft = 3,300,000$

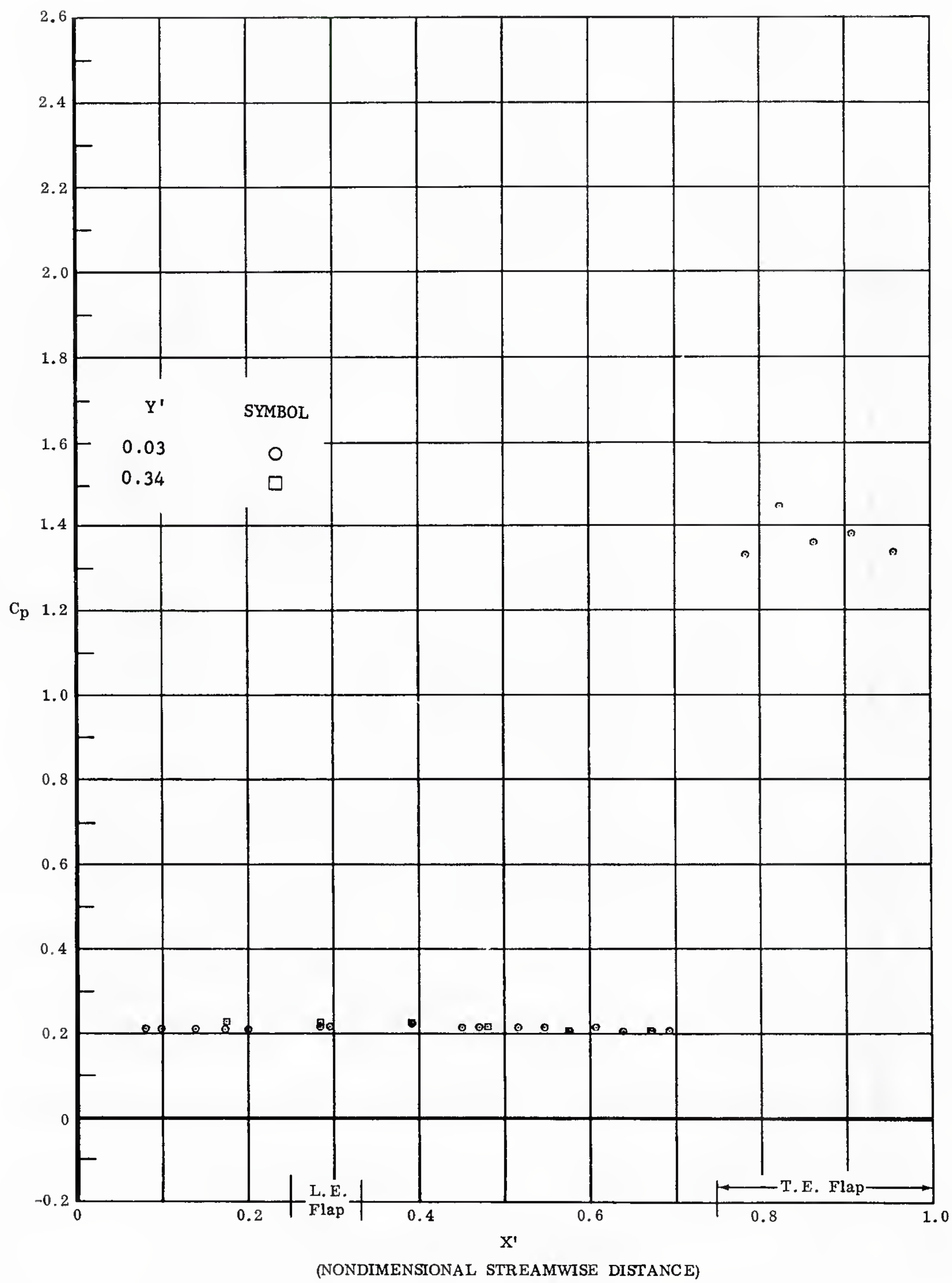


Fig. 8 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 20°, α = -15°, Re_∞/ft = 3,300,000

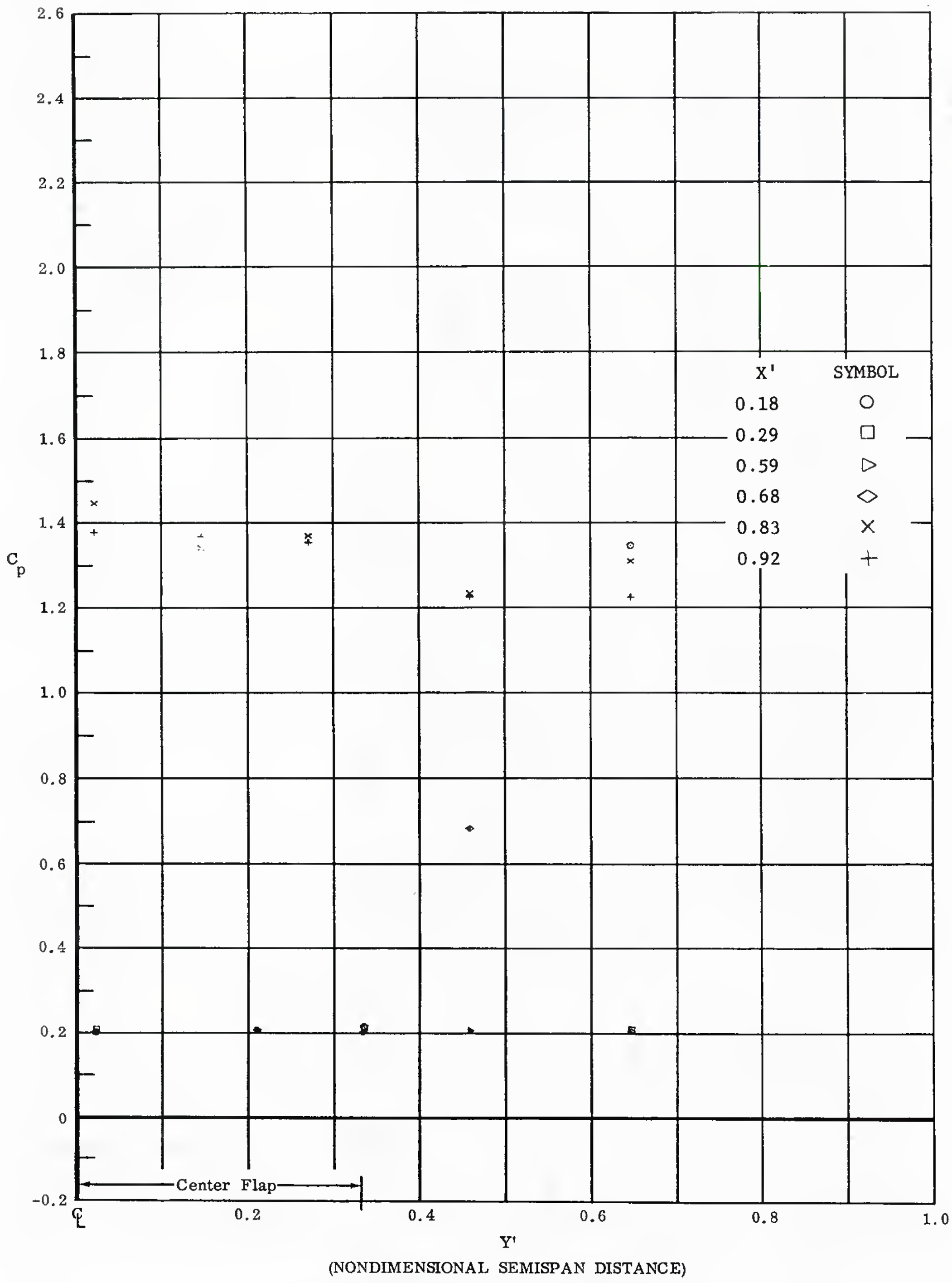


Fig. 8 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 20°, $\alpha = -15°$, $Re_\infty/ft = 3{,}300{,}000$

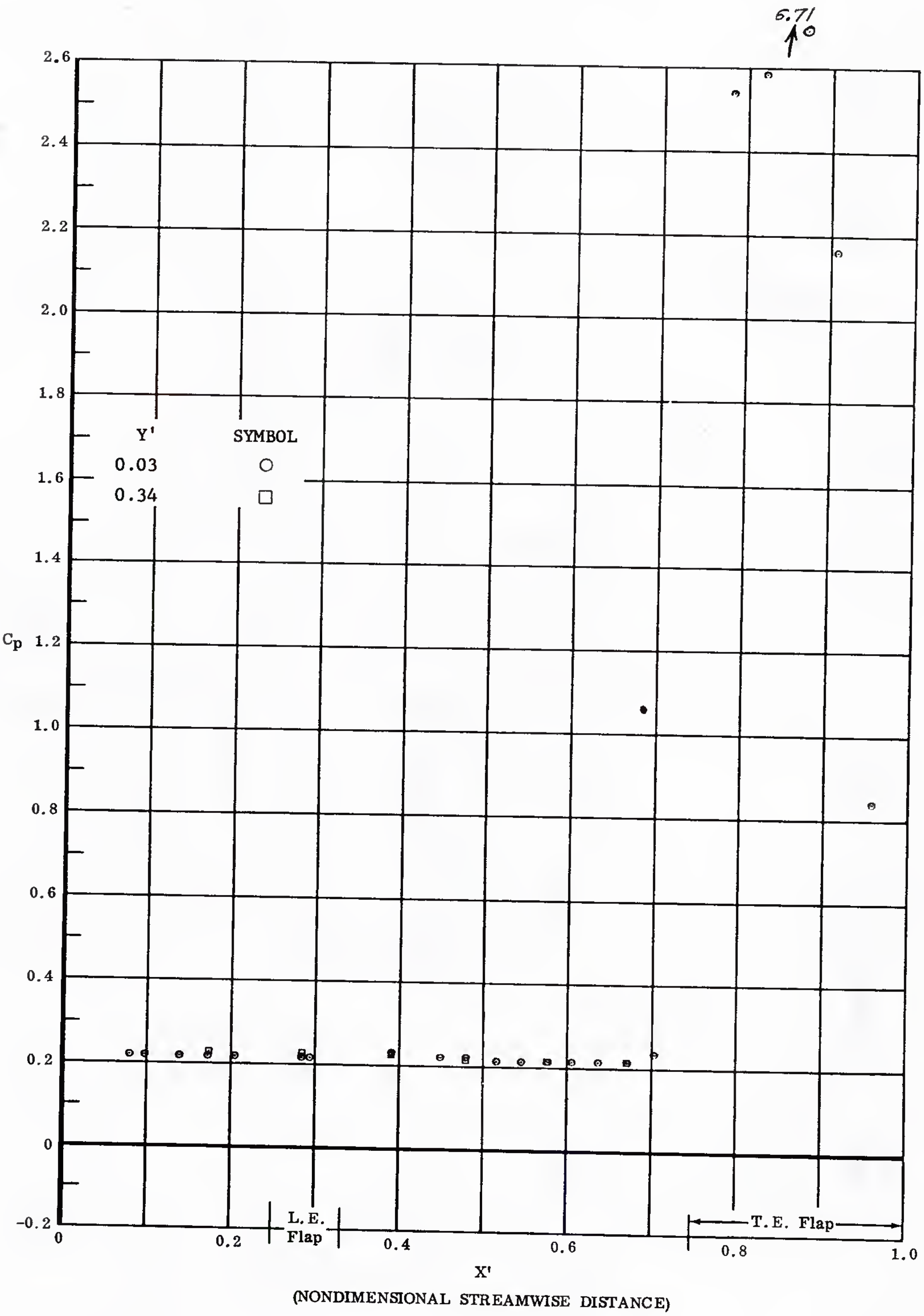


Fig. 9 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = -15°$, Re_∞/ft = 3,300,000

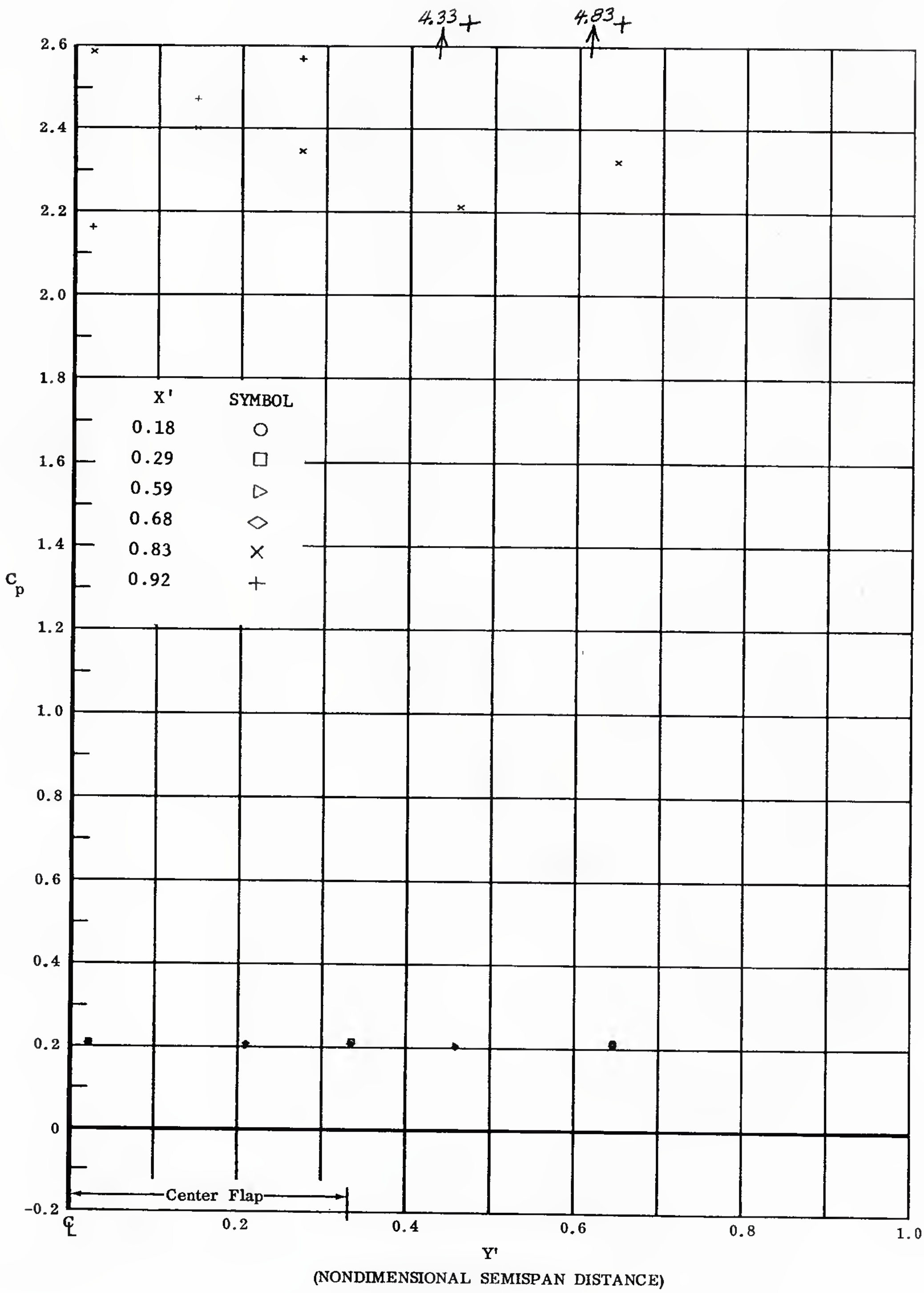


Fig. 9 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = -15°$, $Re_\infty/ft = 3{,}300{,}000$

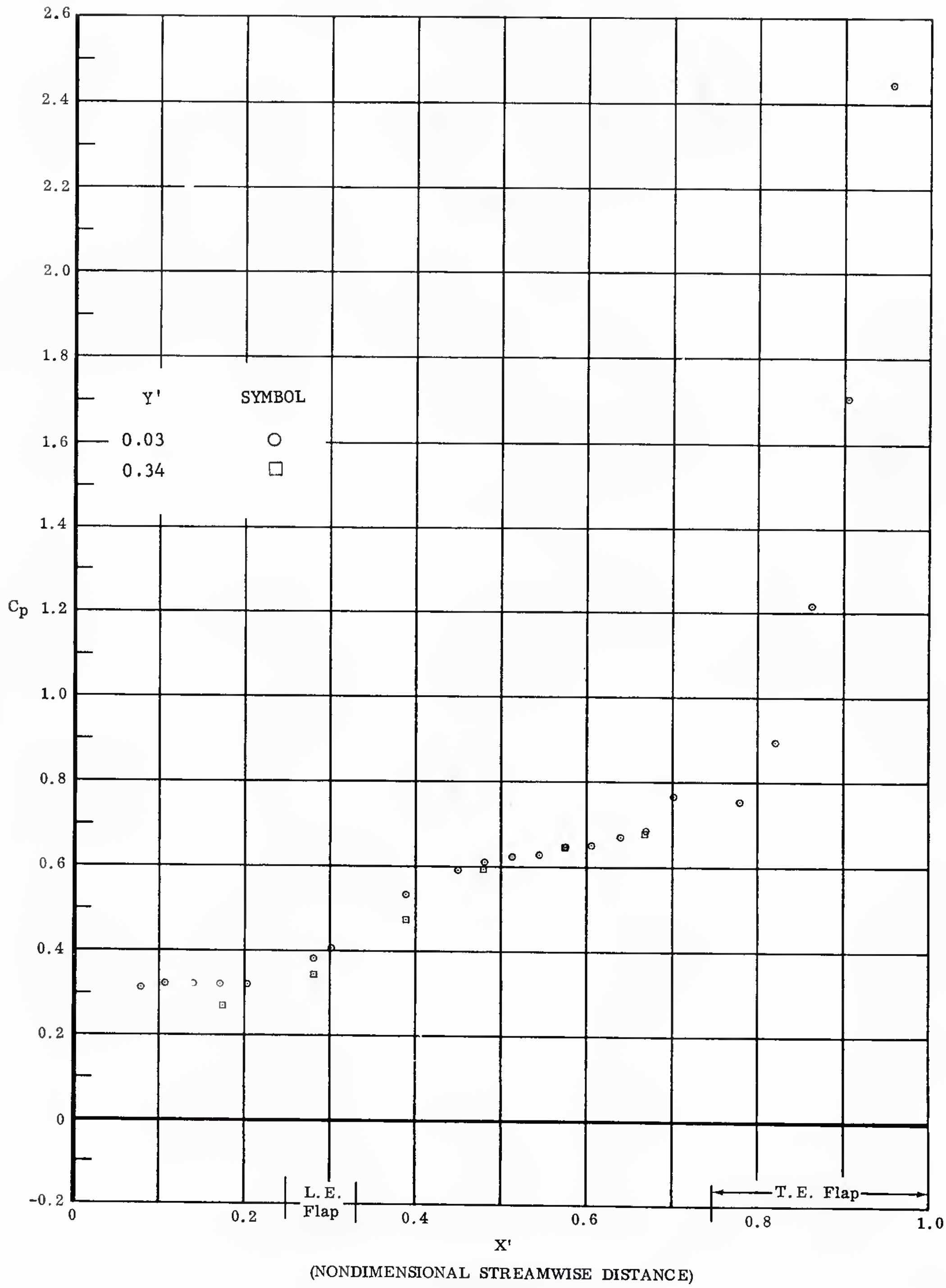


Fig. 10 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, α = -15°, Re_∞/ft = 3,300,000

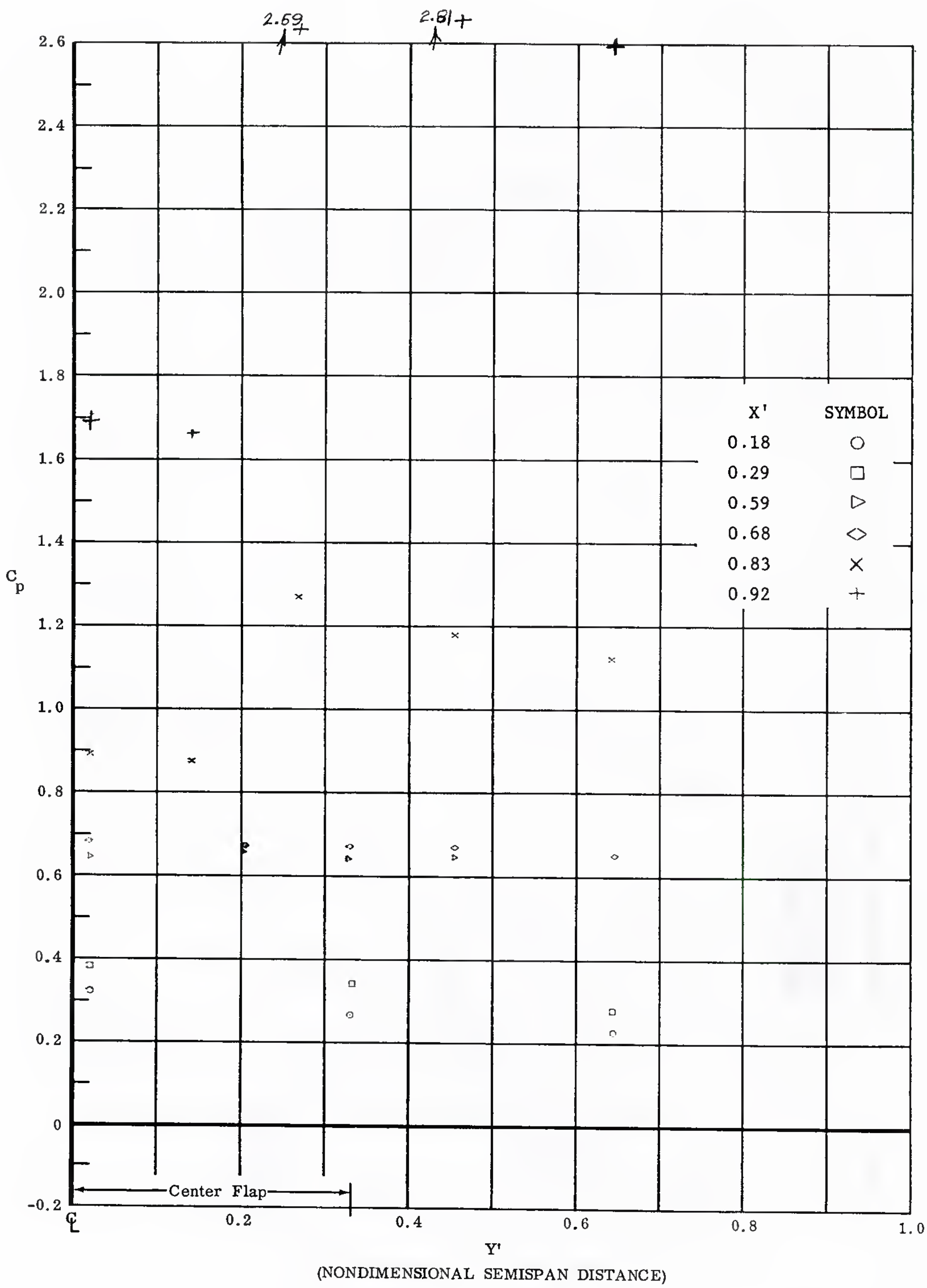


Fig. 10 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, α = -15°, R_{e_∞}/ft = 3,300,000

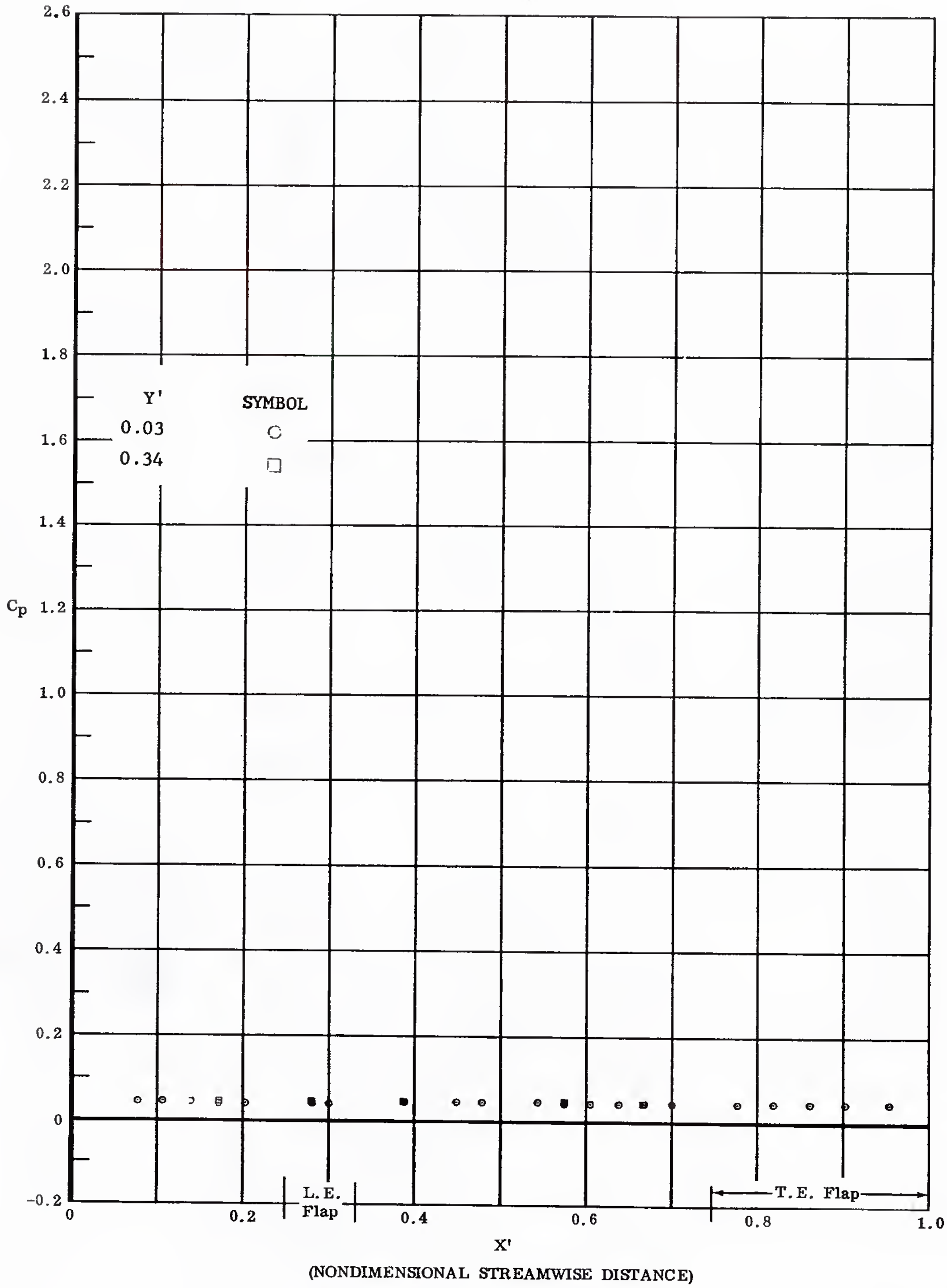


Fig. 11 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$

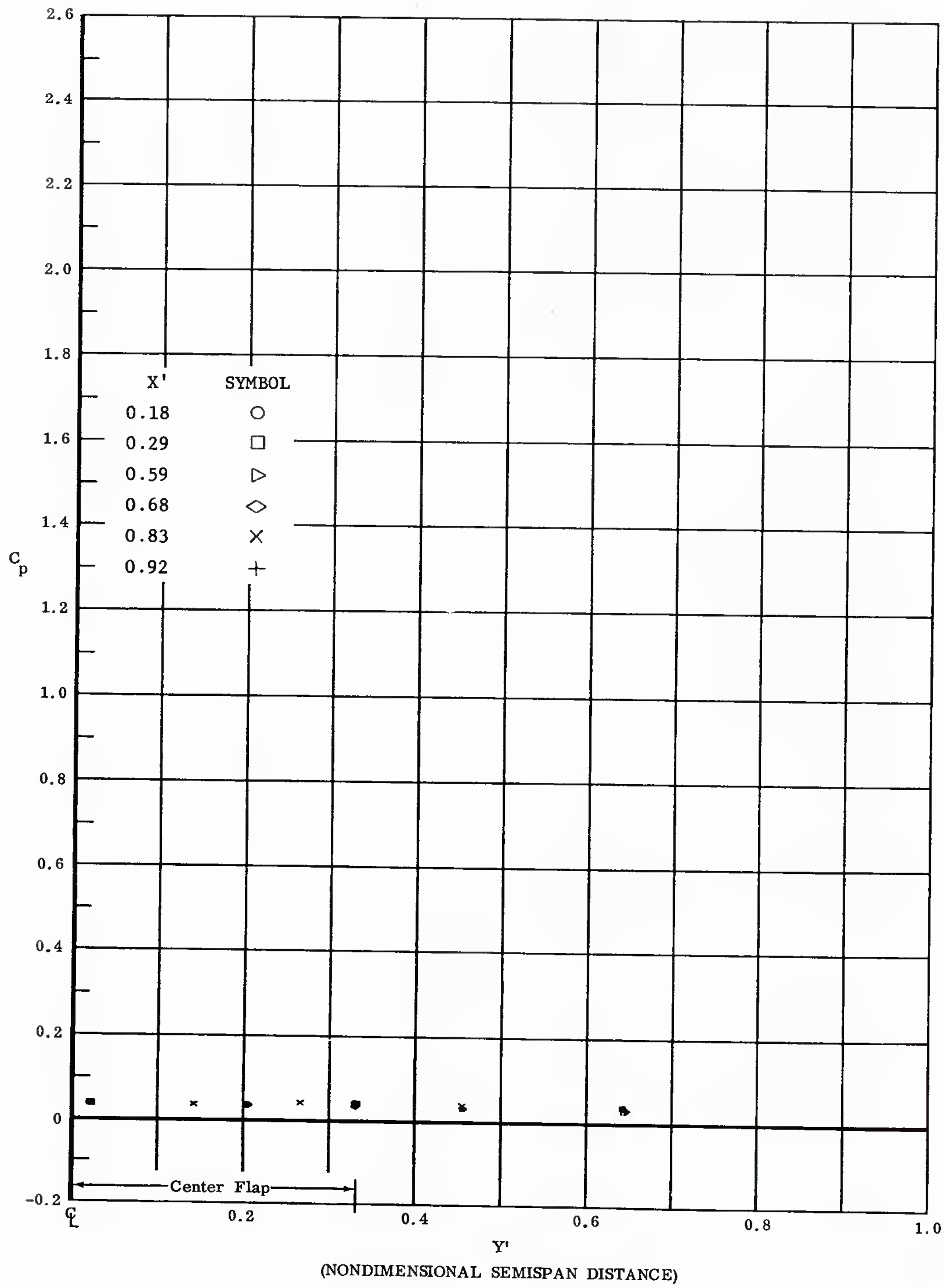


Fig. 11 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = -5°$, $Re_\infty/ft = 3,300,000$

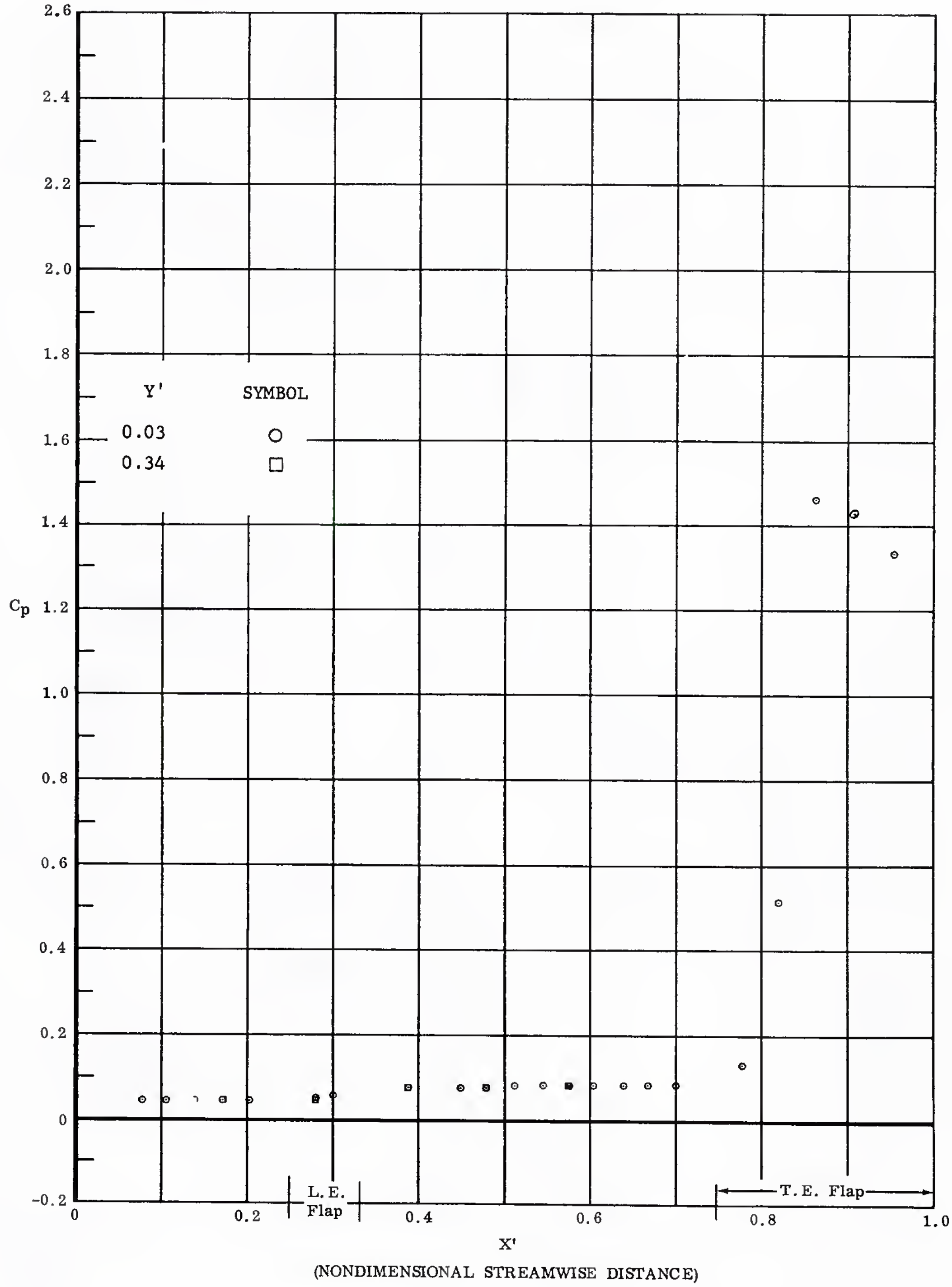


Fig. 12 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = -5°$, $Re_\infty/ft = 3{,}300{,}000$

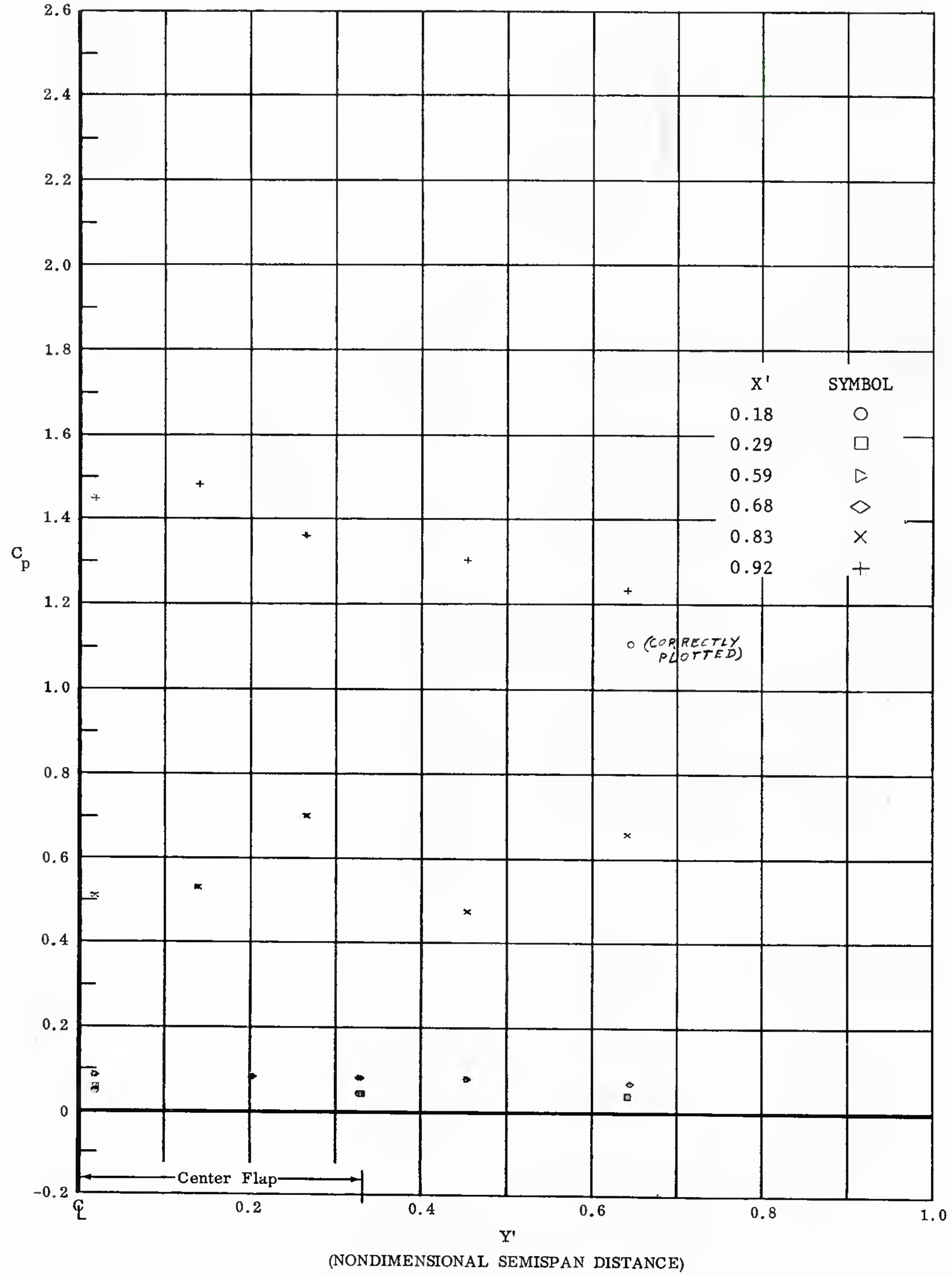


Fig. 12 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = -5°$, $Re_\infty/ft = 3{,}300{,}000$

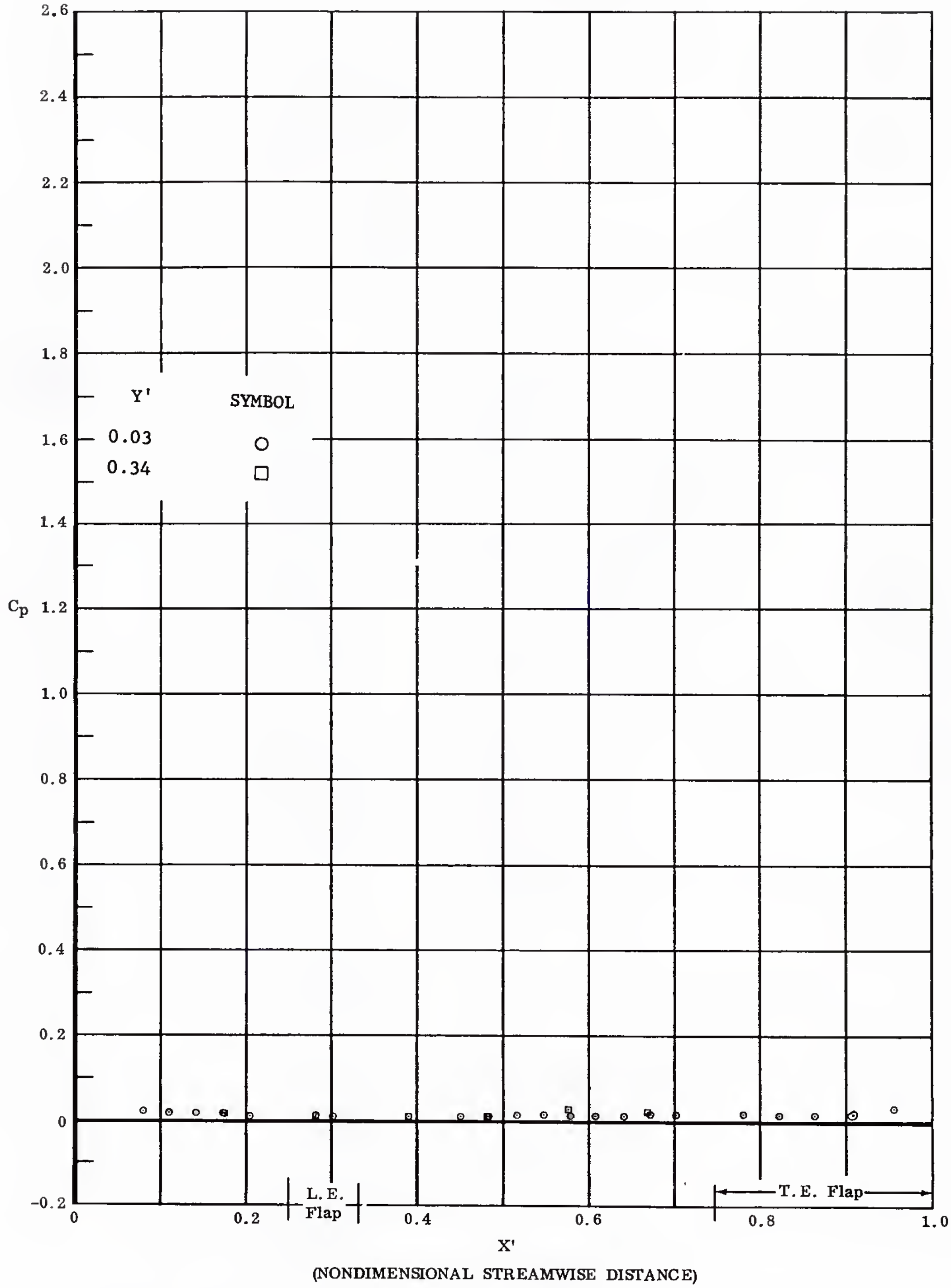


Fig. 13 Streamwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

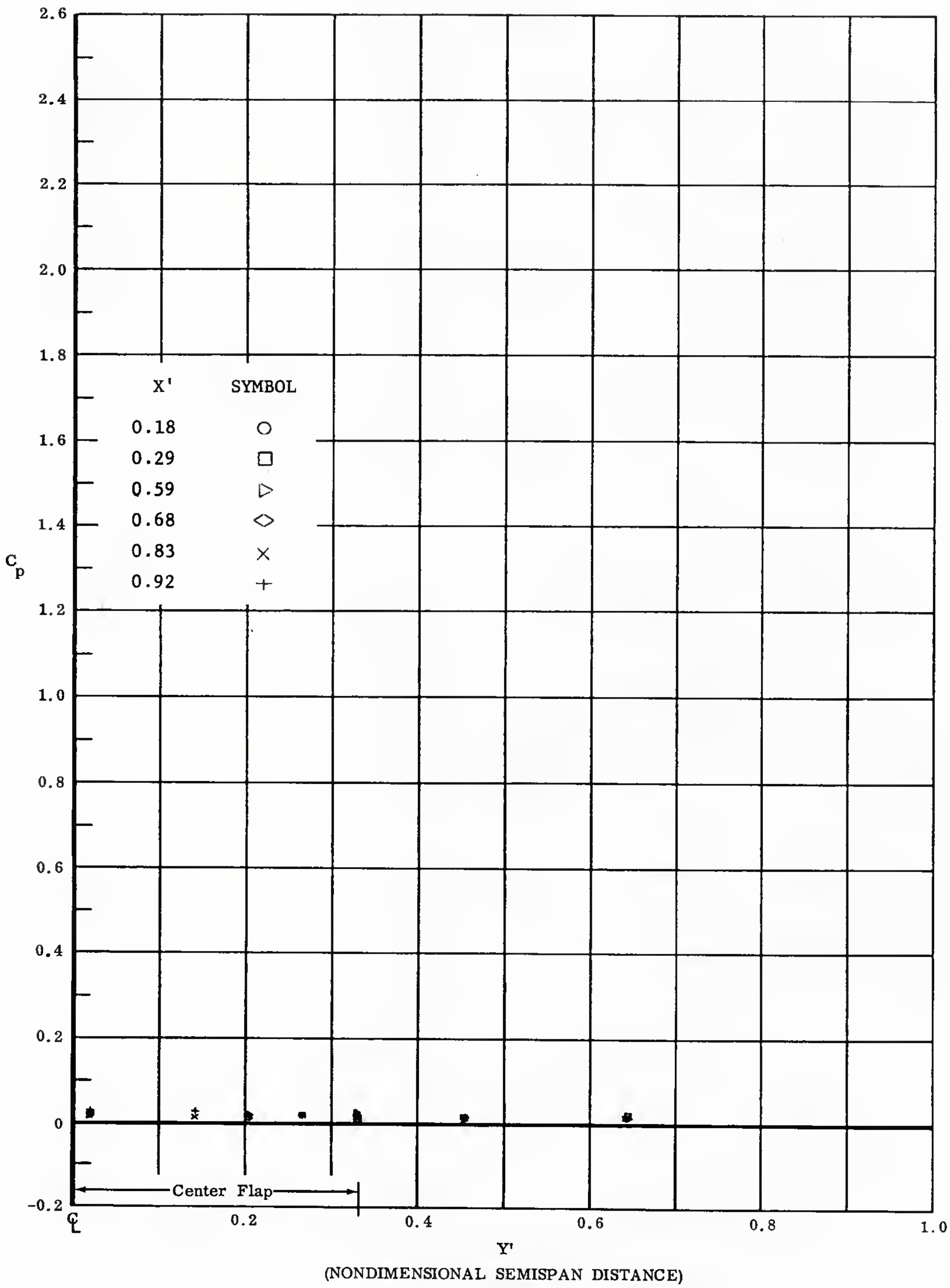


Fig. 13 Spanwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

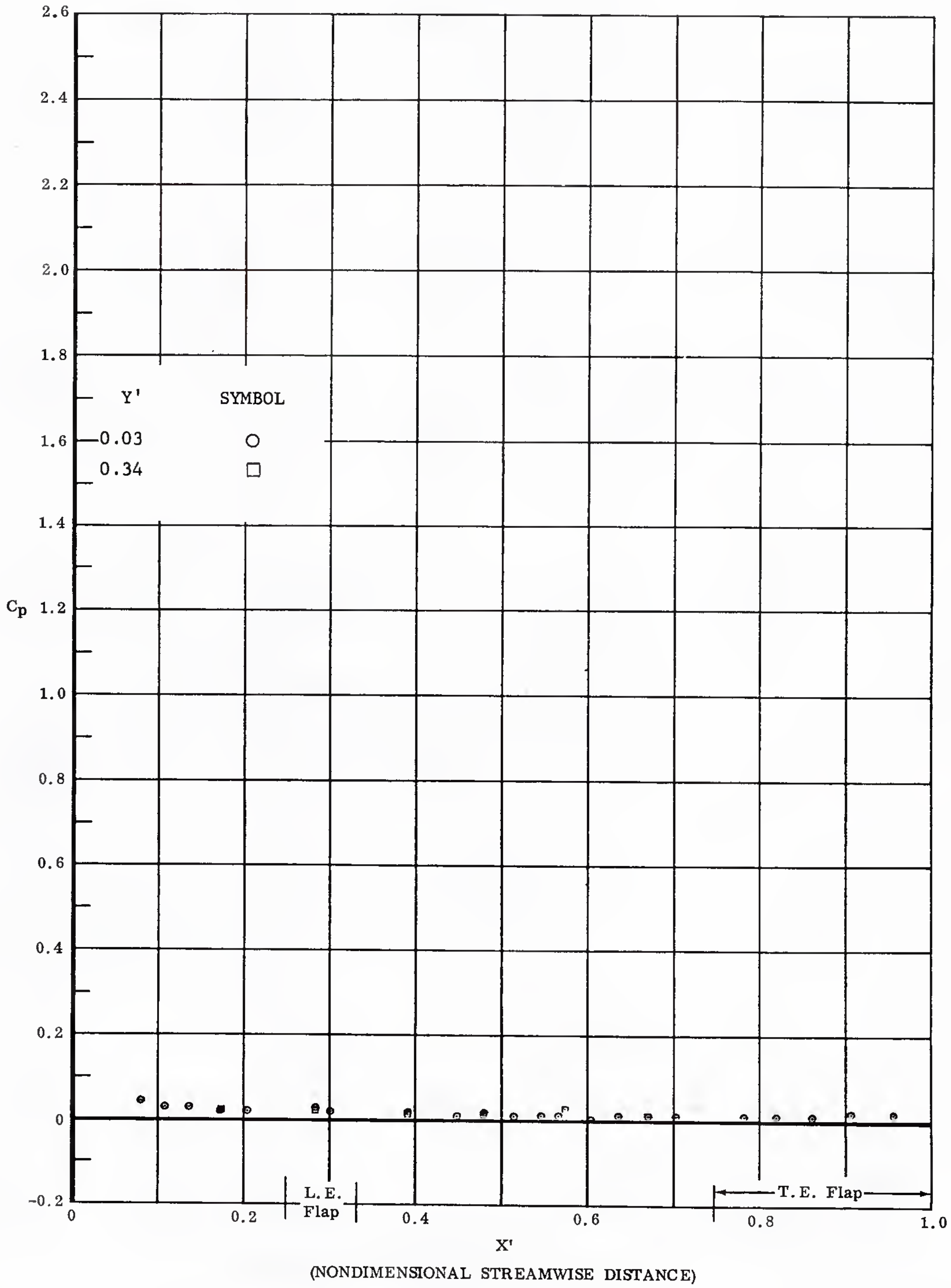


Fig. 14 Streamwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

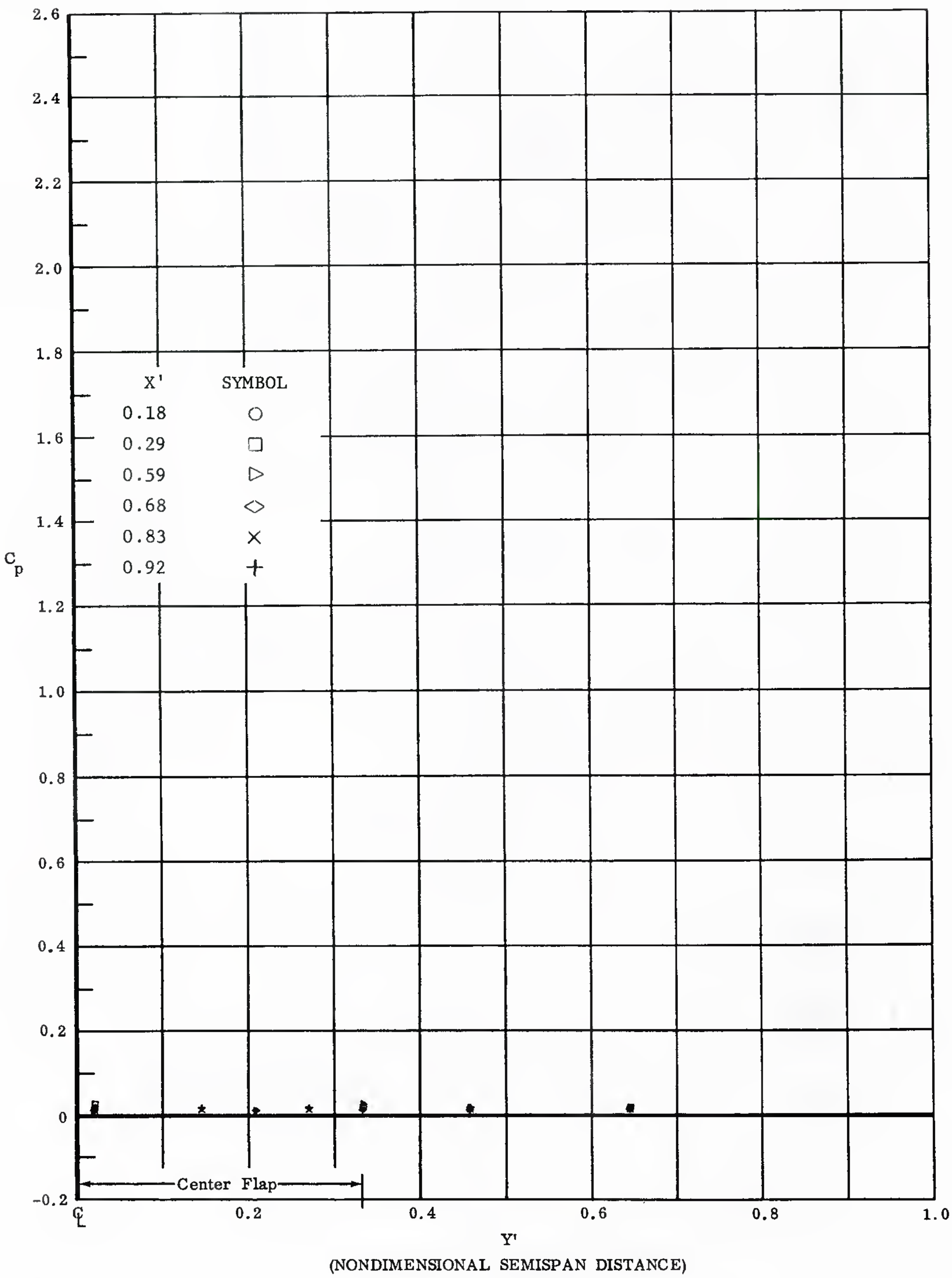


Fig. 14 Spanwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_{\infty}/ft = 1{,}100{,}000$

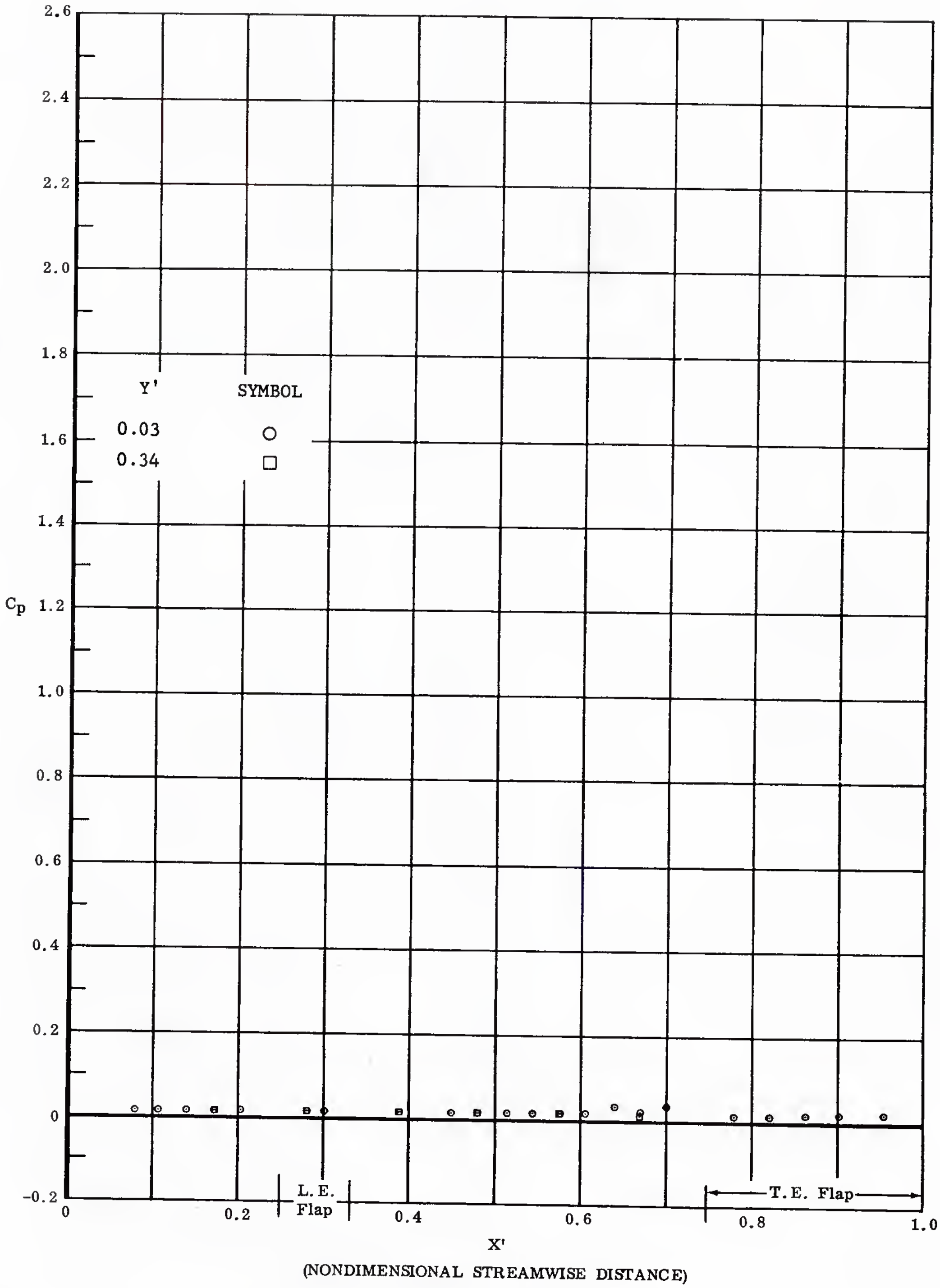


Fig. 15 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = 0$, $Re_\infty/ft = 2,200,000$

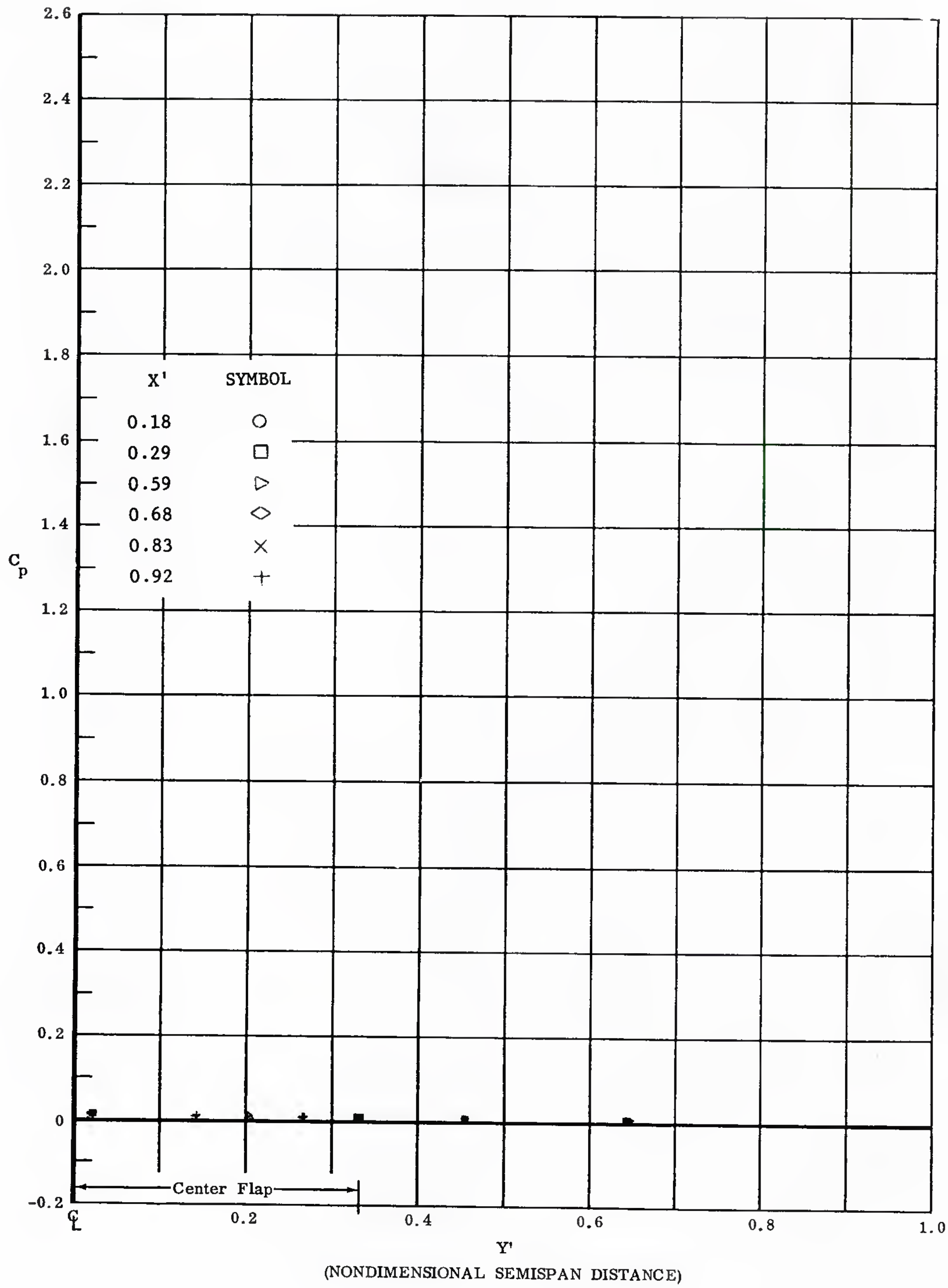


Fig. 15 Spanwise Pressure Distributions: End Plates Off, No Flap Deflections, $\alpha = 0$, $Re_{\infty}/ft = 2,200,000$.

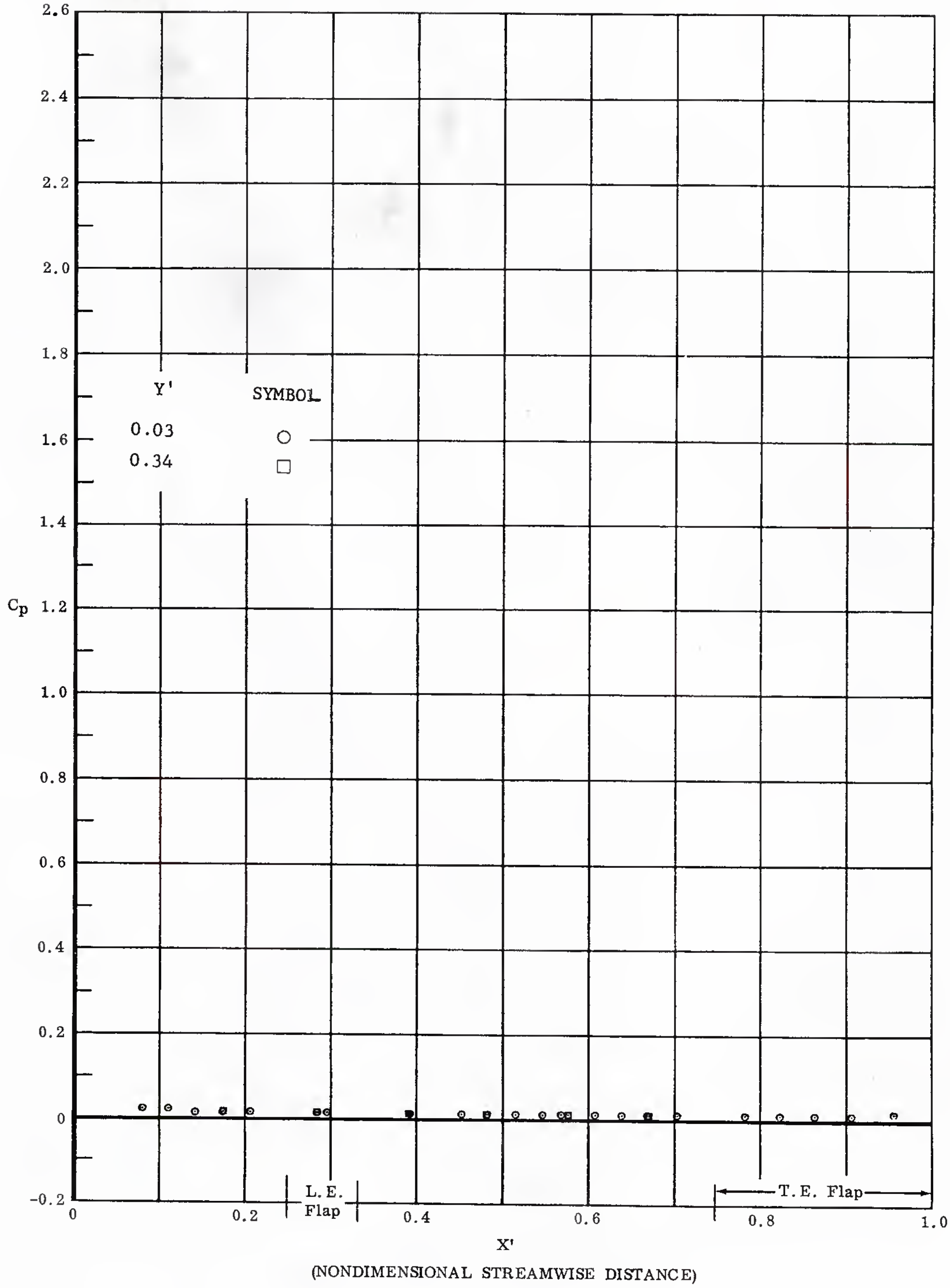


Fig. 16 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = 0$, $Re_{\infty}/ft = 3{,}300{,}000$

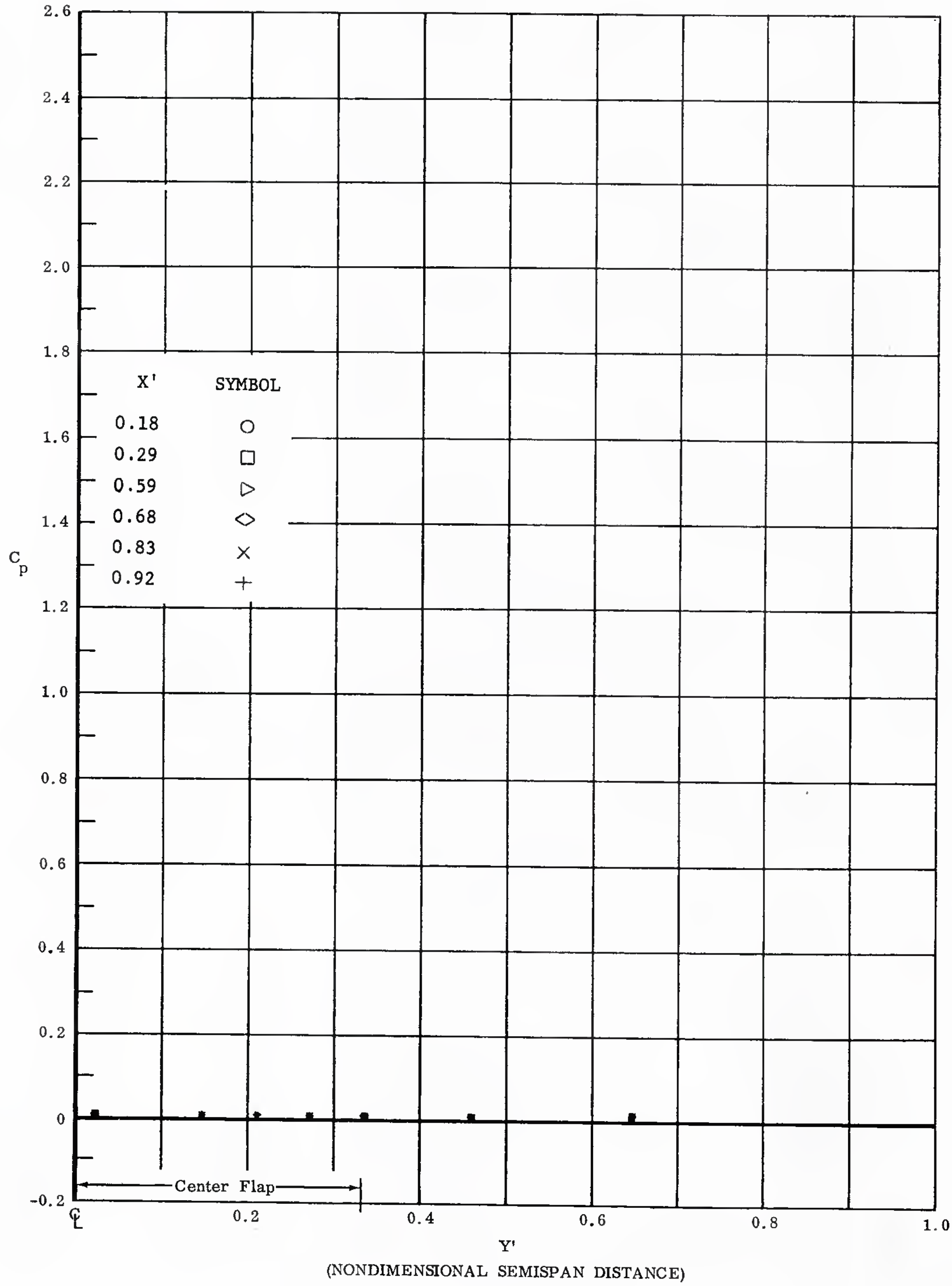


Fig. 16 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = 0$, $Re_{\infty}/ft = 3{,}300{,}000$

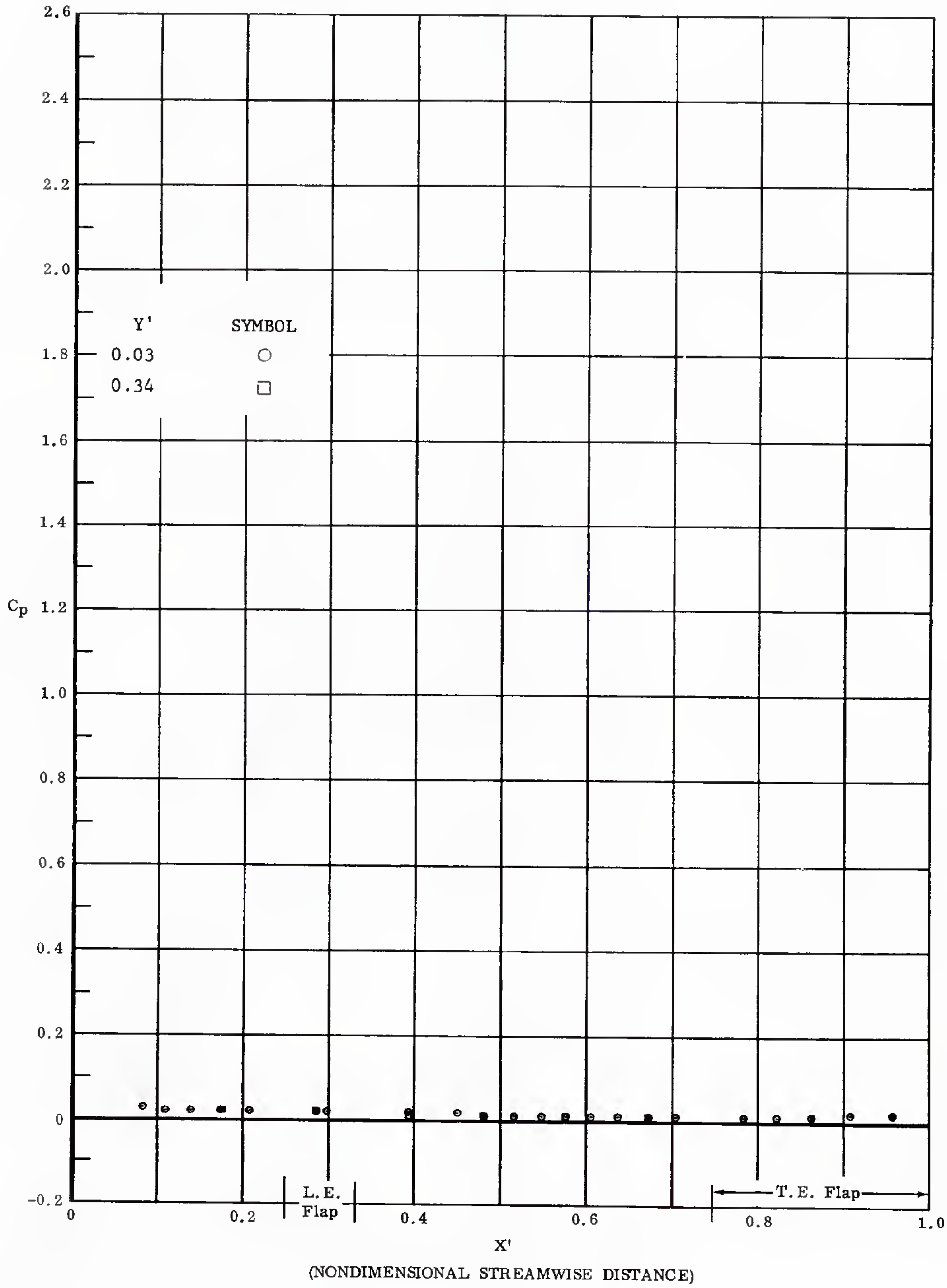


Fig. 17 Streamwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

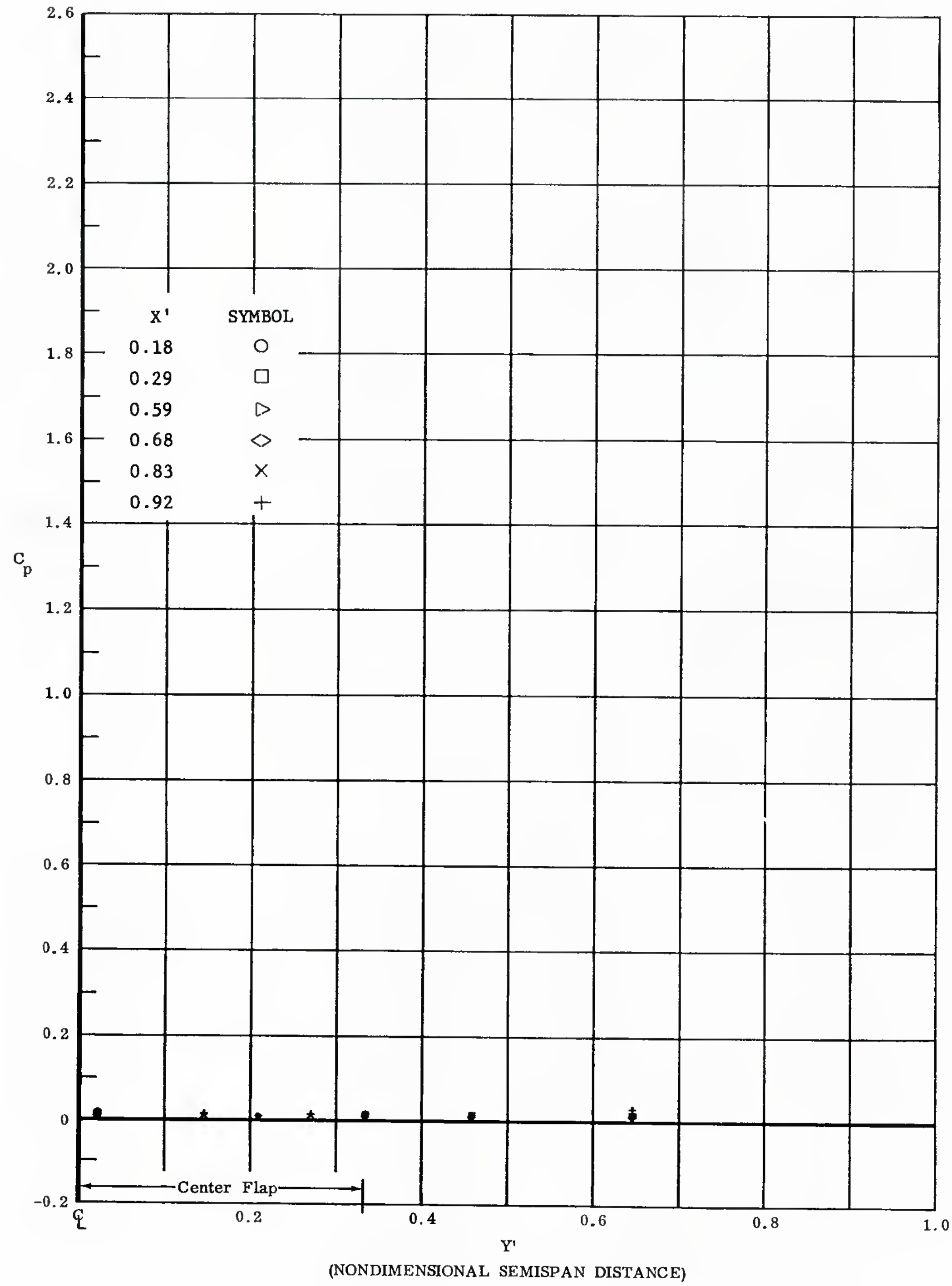


Fig. 17 Spanwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = 0$, $Re_{\infty}/ft = 3{,}300{,}000$

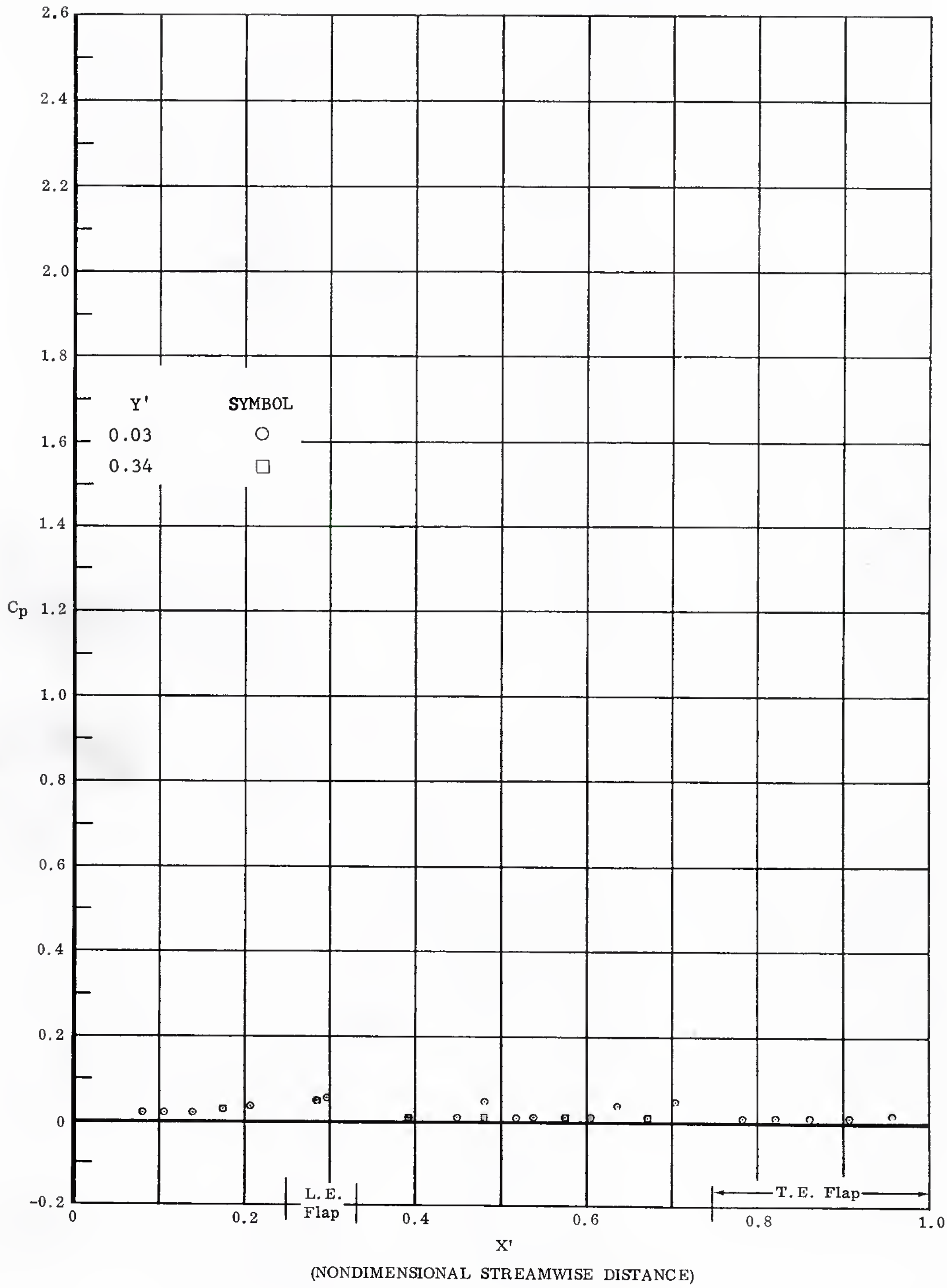


Fig. 18 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 3,300,00$

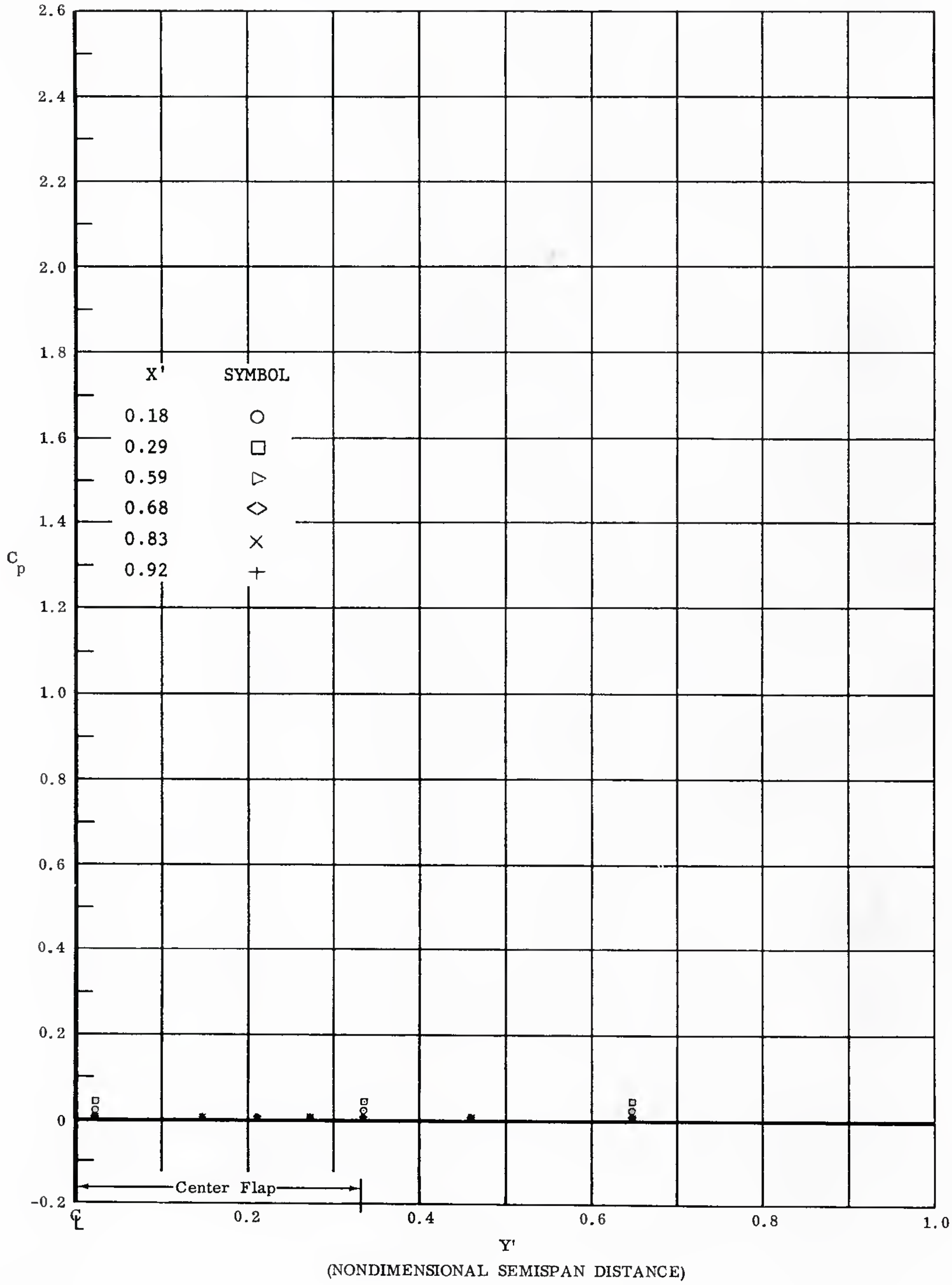


Fig. 18 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 10°, α= 0, Re_∞/ft = 3,300,000

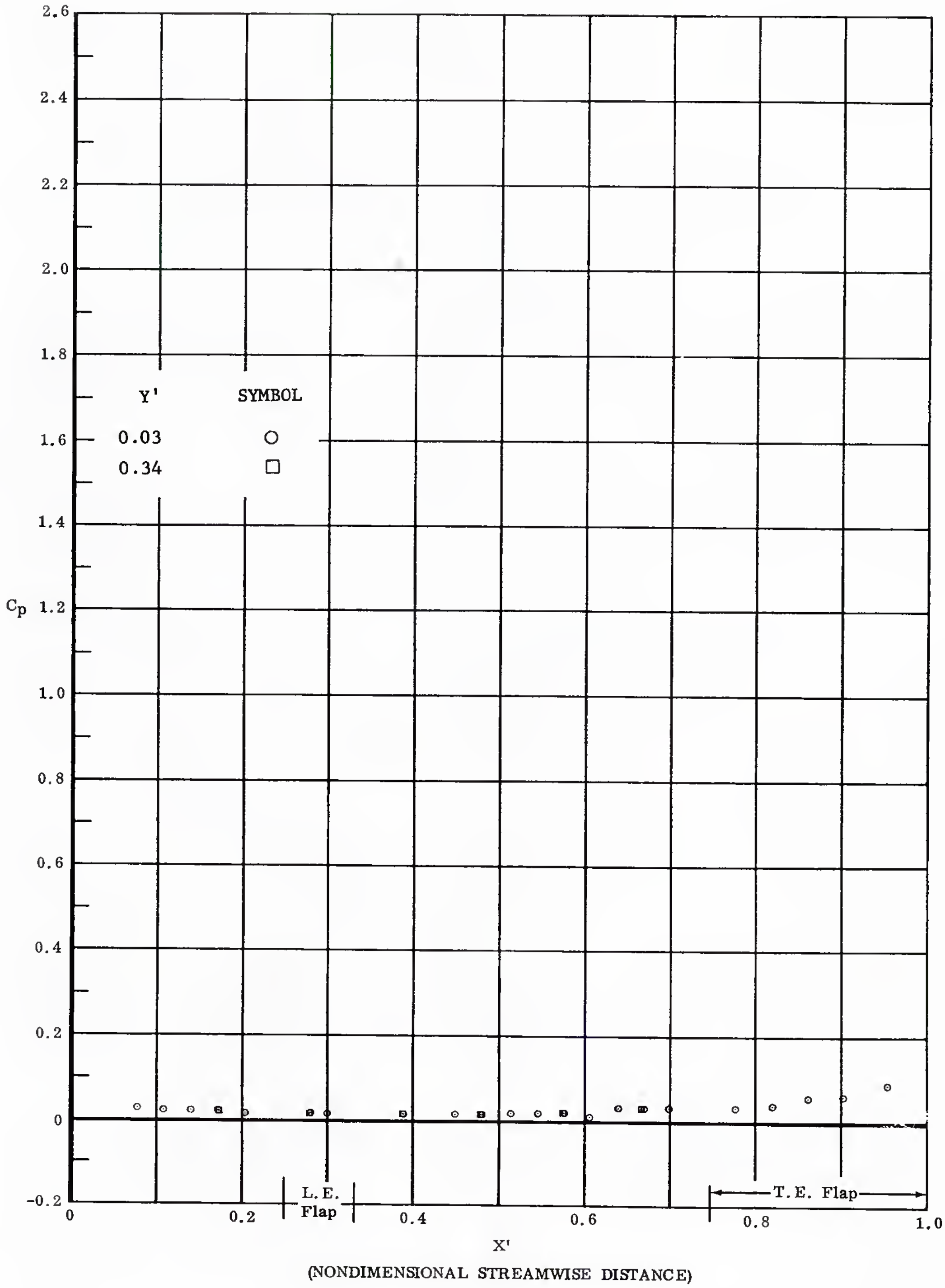


Fig. 19 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

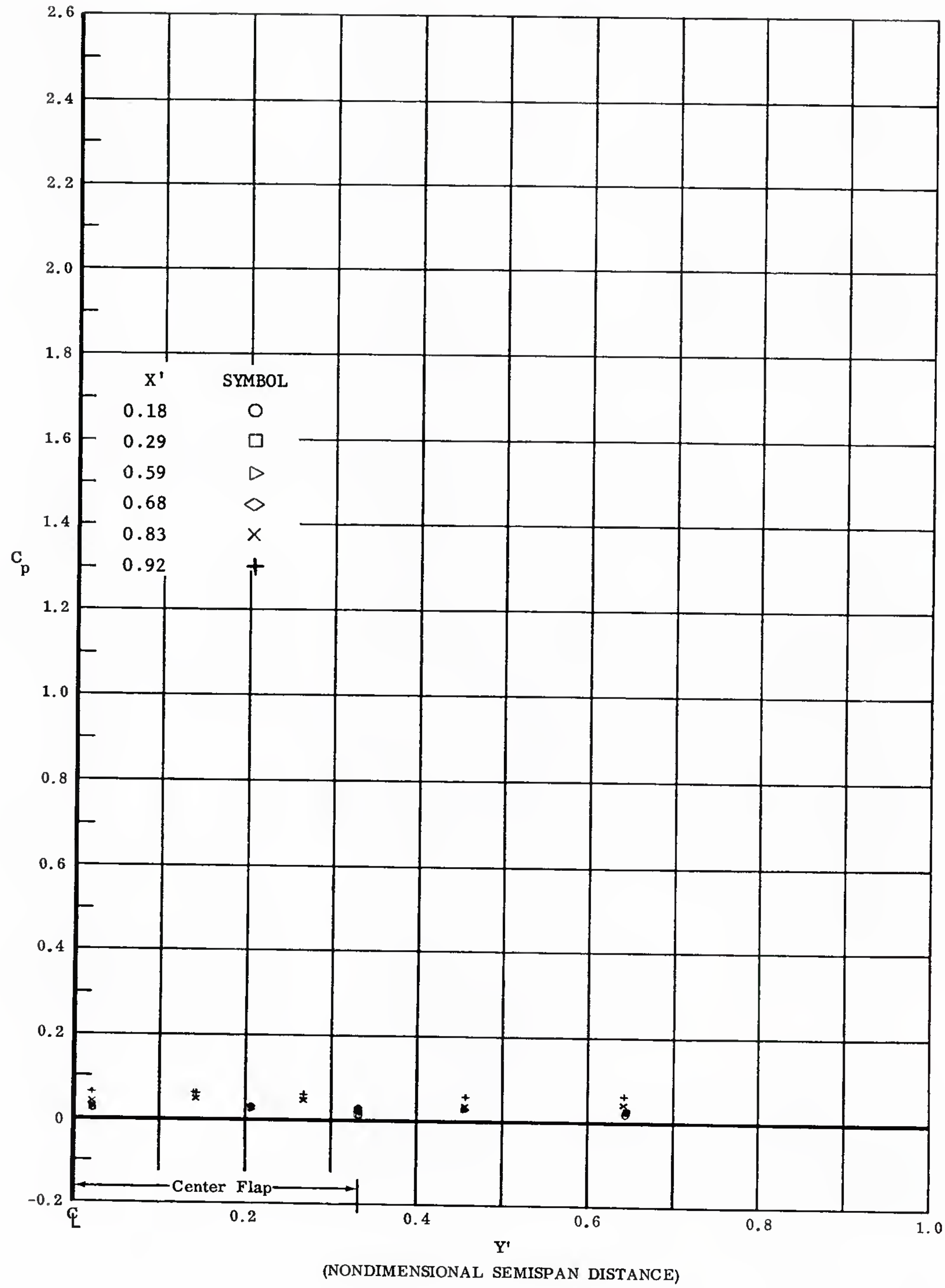


Fig. 19 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

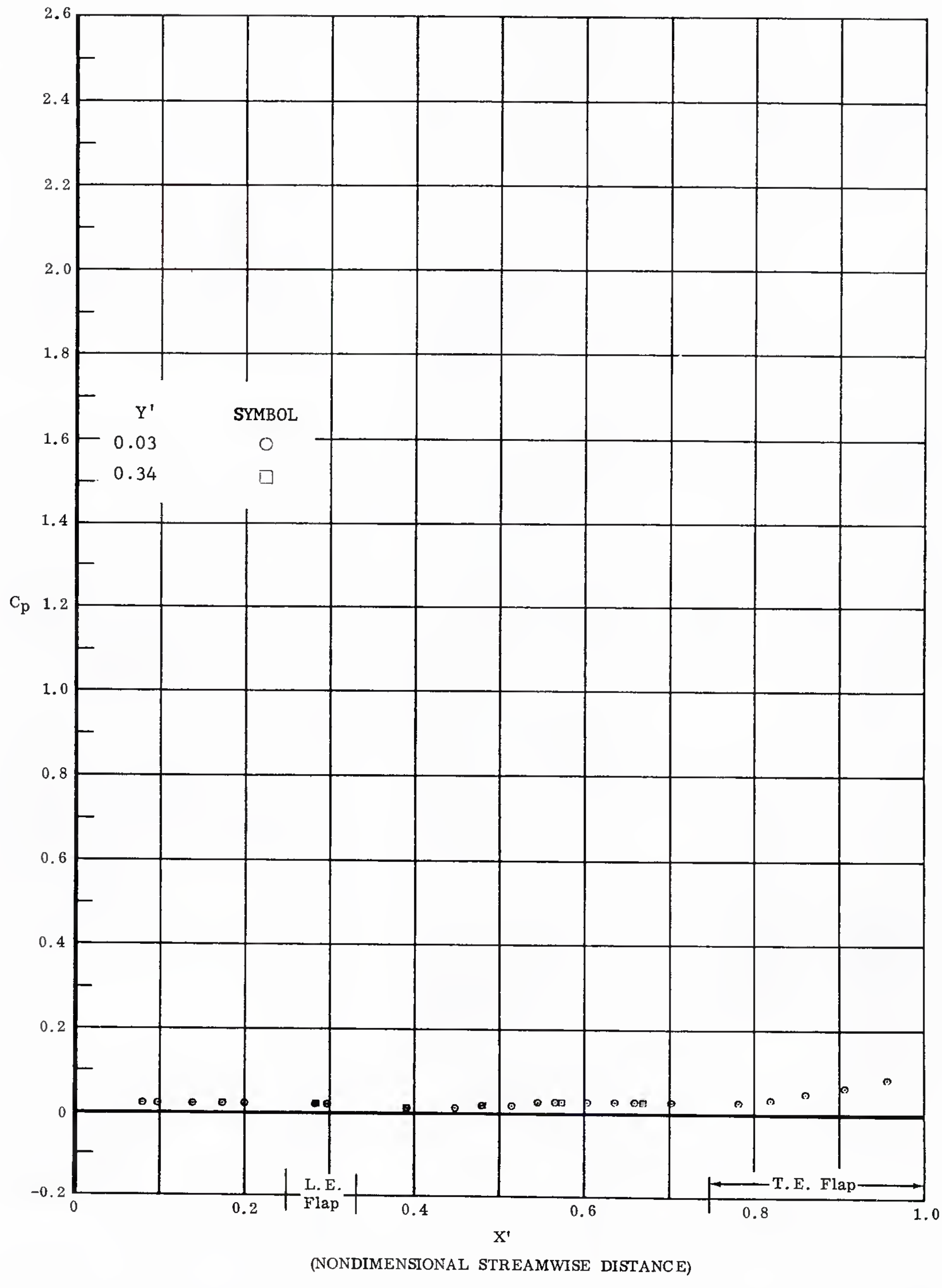


Fig. 20 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 10°, $\alpha = 0$, R_{e_∞}/ft = 3,300,000

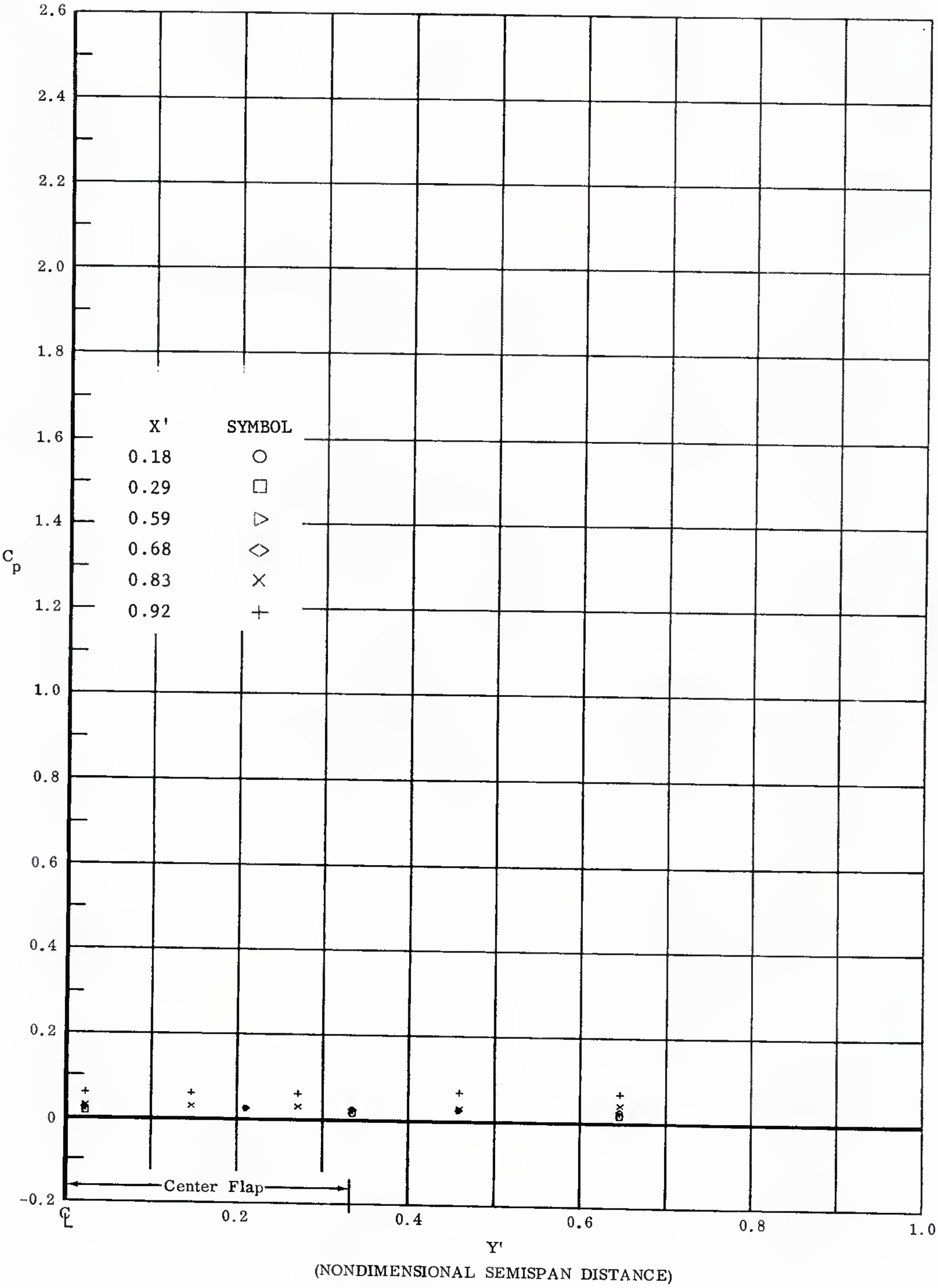


Fig. 20 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

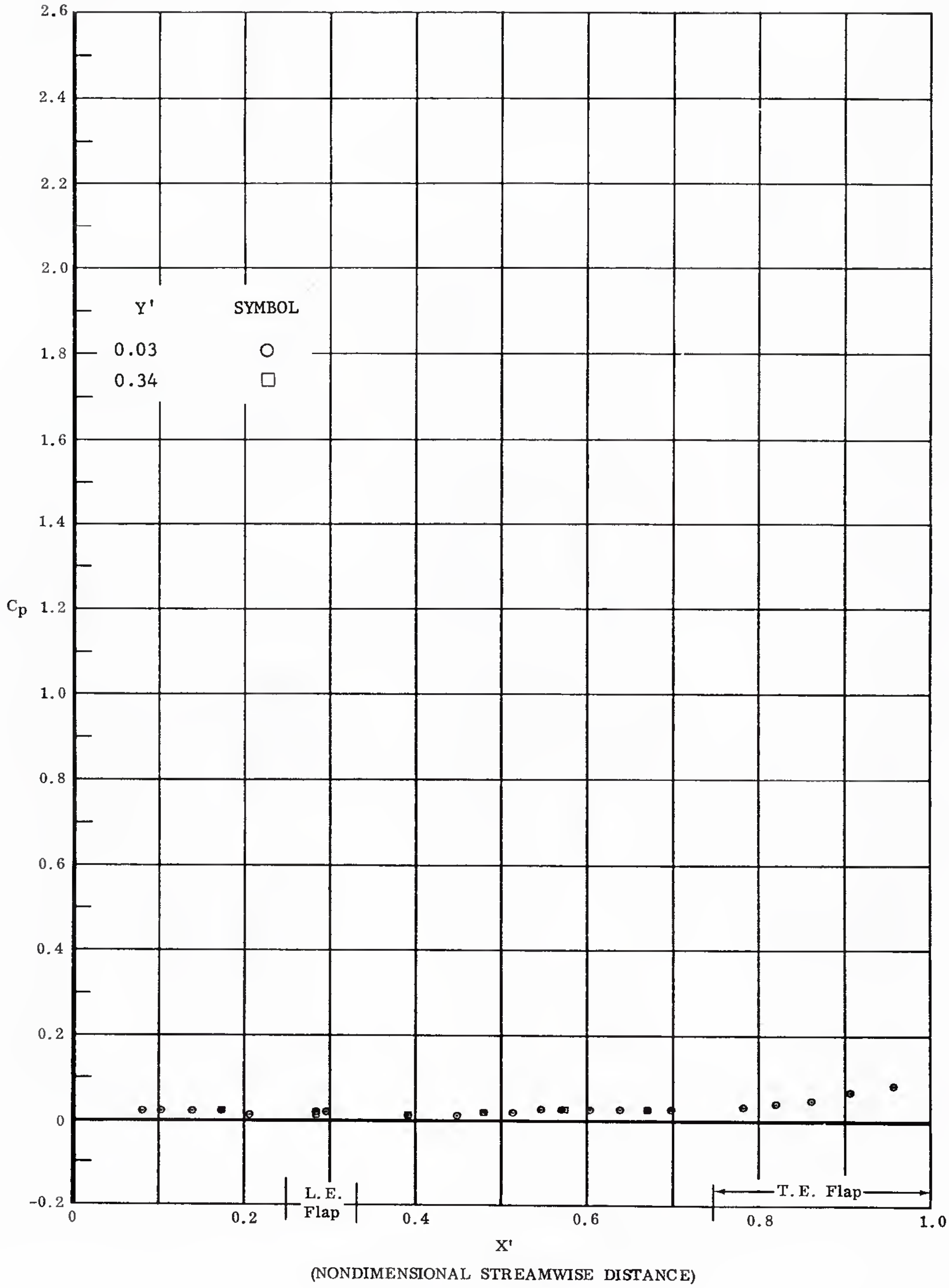


Fig. 21 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

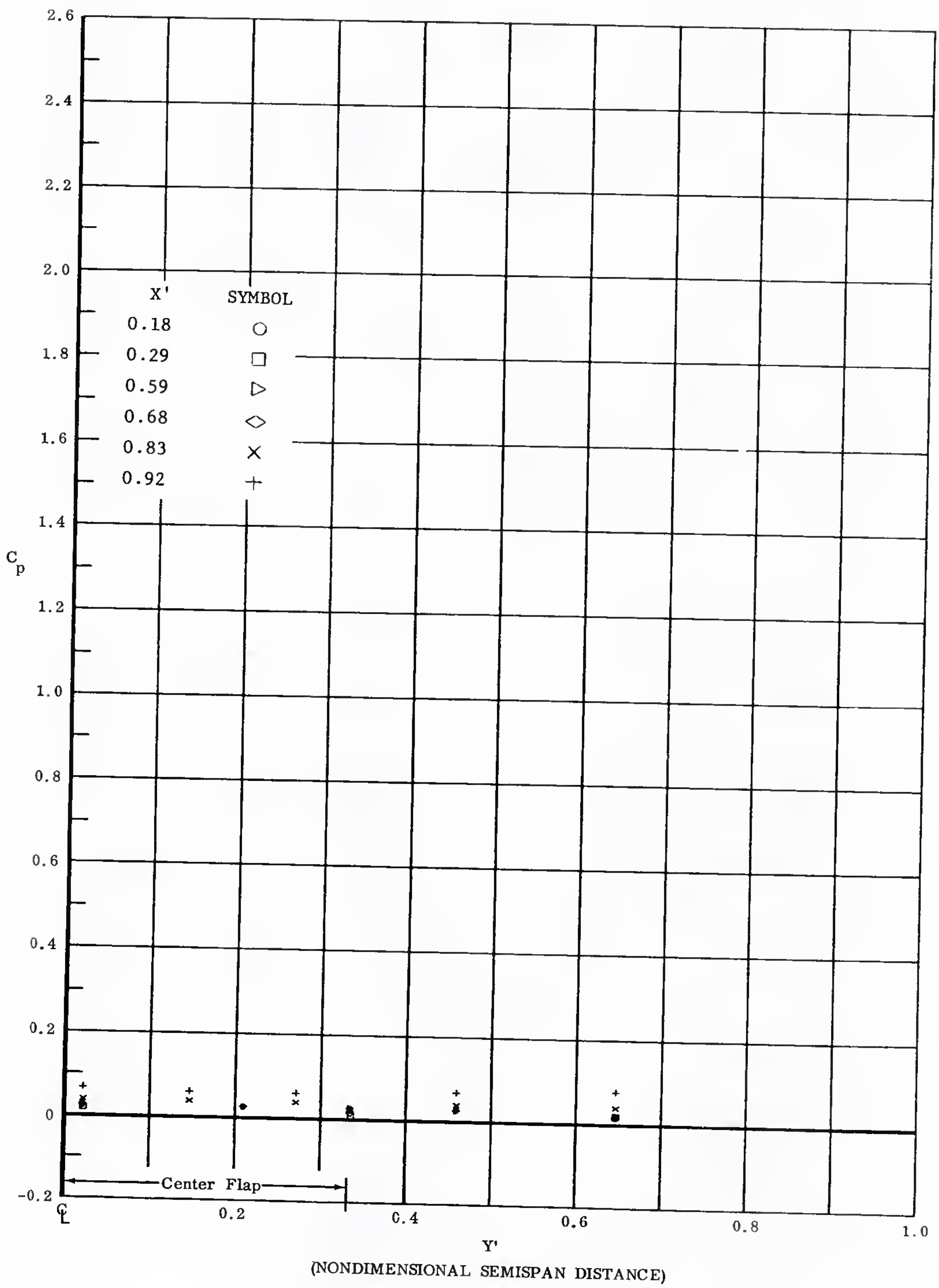


Fig. 21 Spanwise Pressure Distributions; End Plates On, [illegible]
Span Flap Deflected 10°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

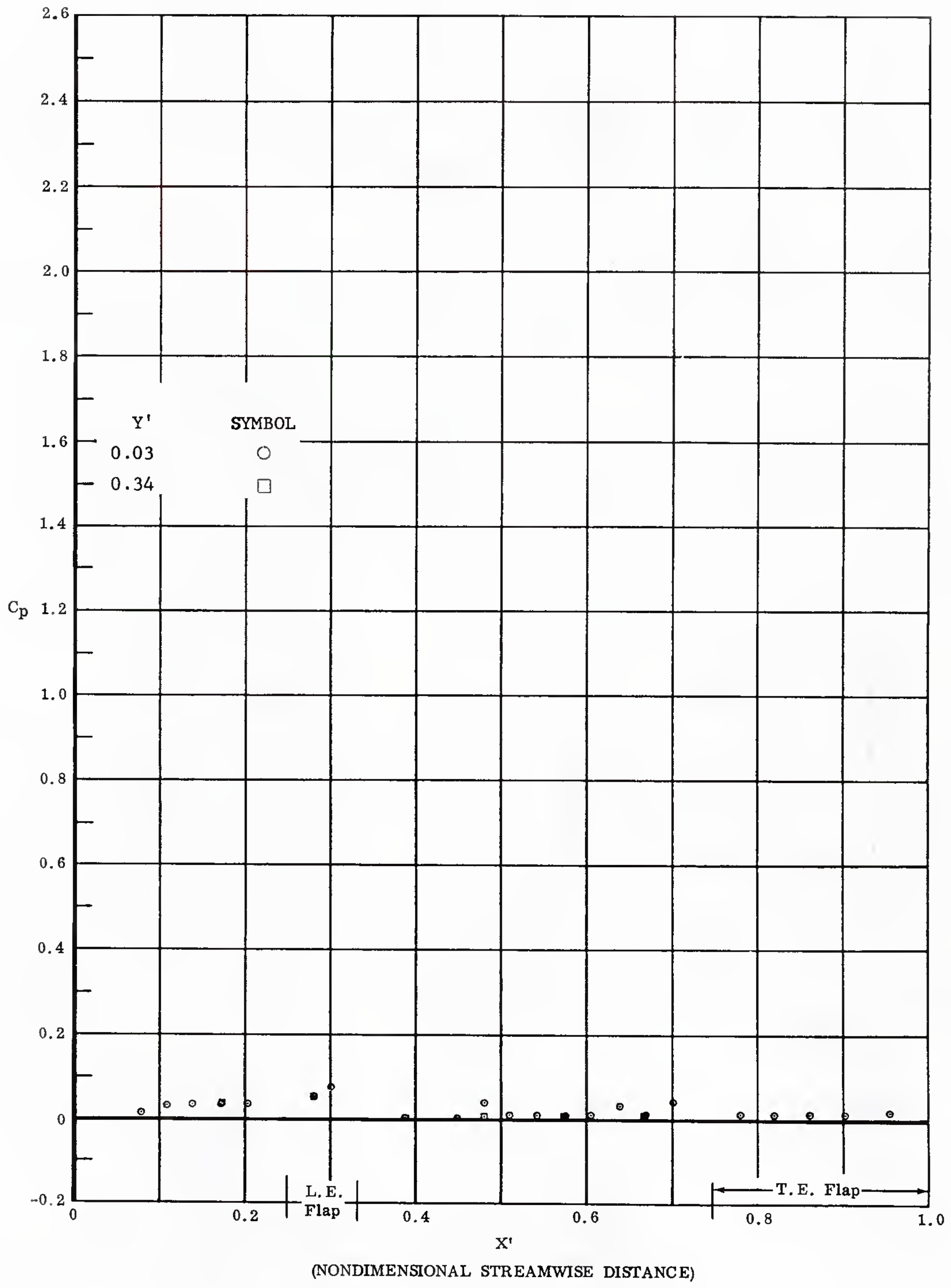


Fig. 22 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 15°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

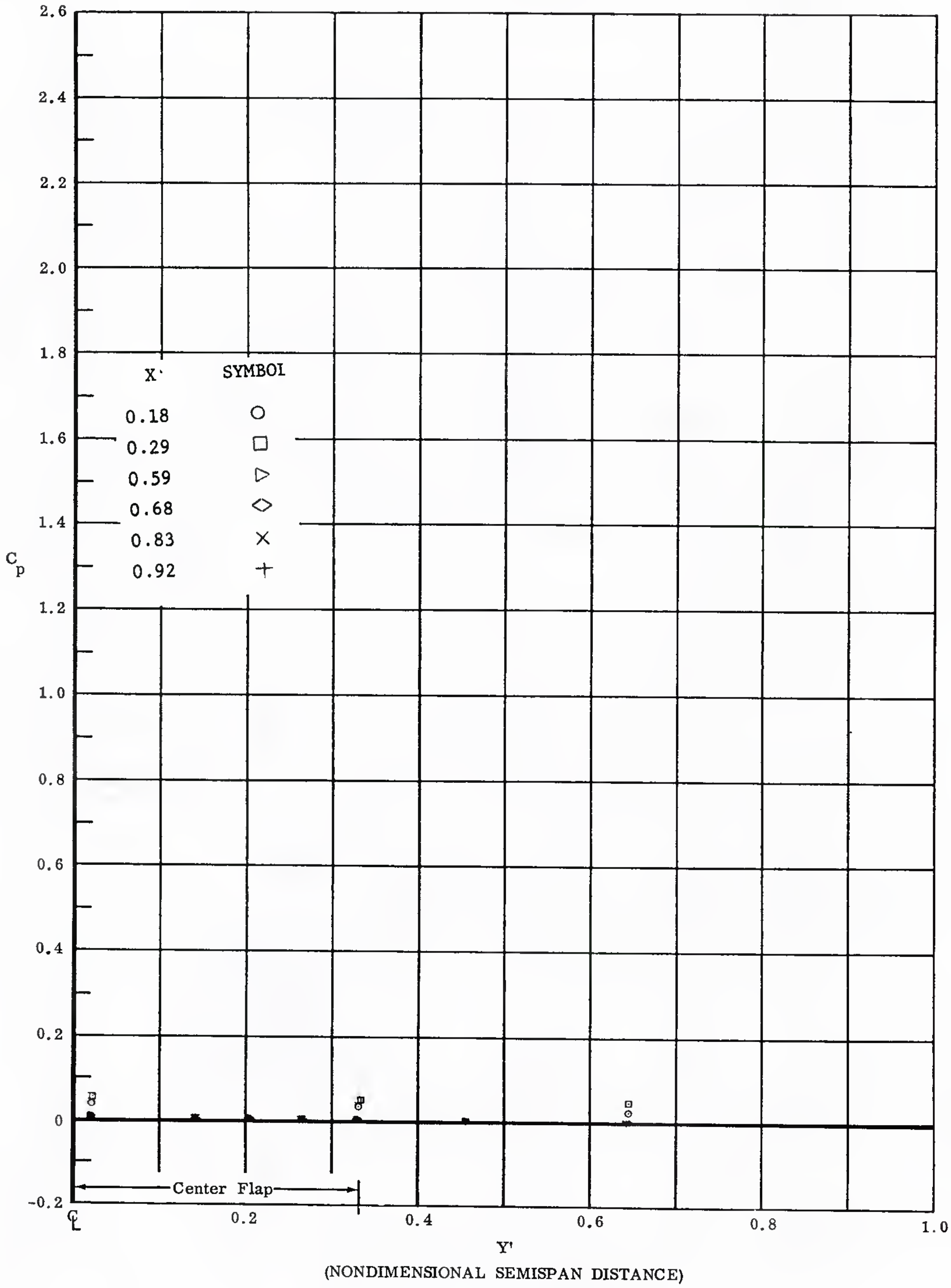


Fig. 22 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 15°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

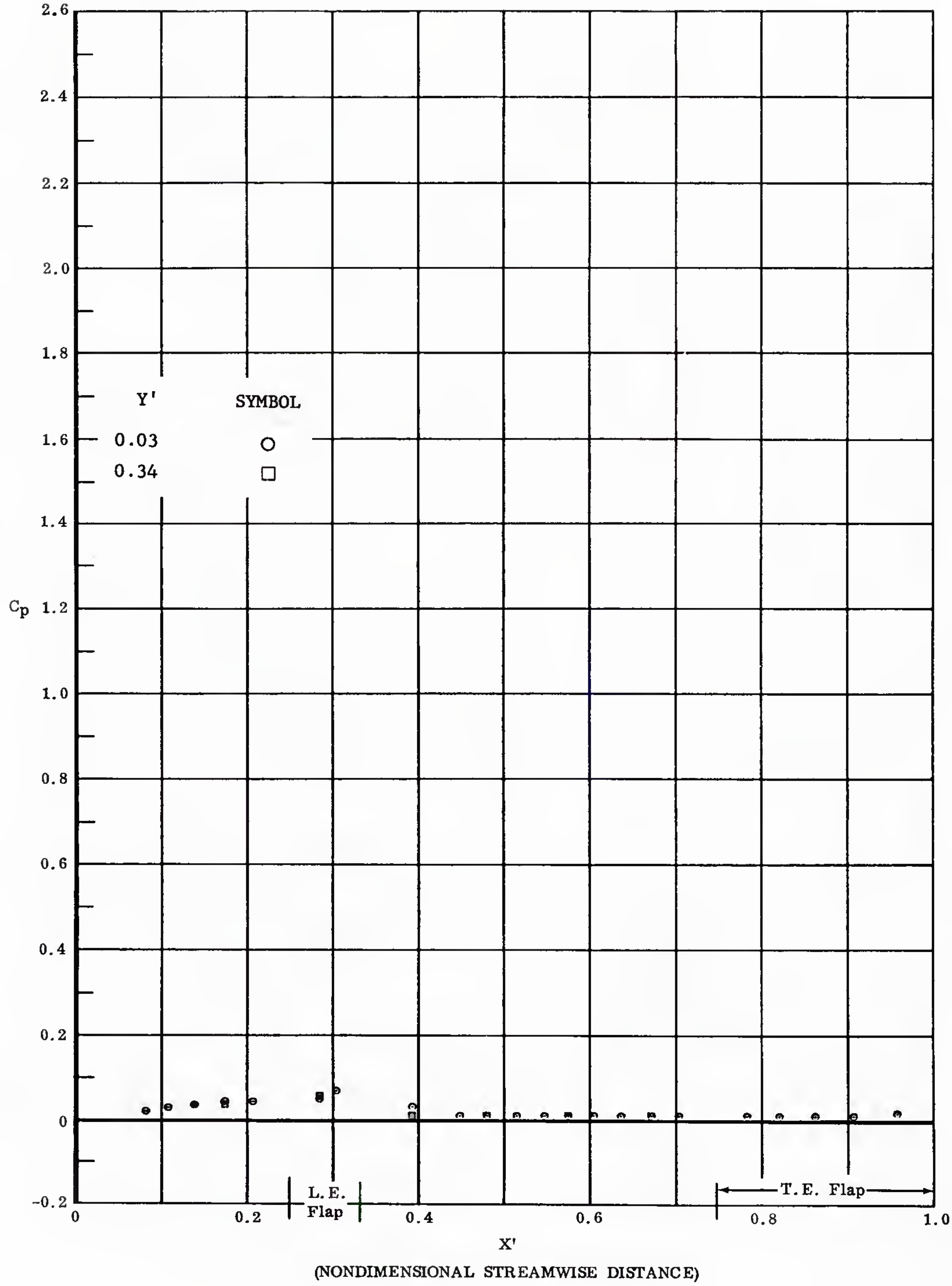


Fig. 23 Streamwise Pressure Distributions; End Plates On, Forward Flap Deflected 15°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

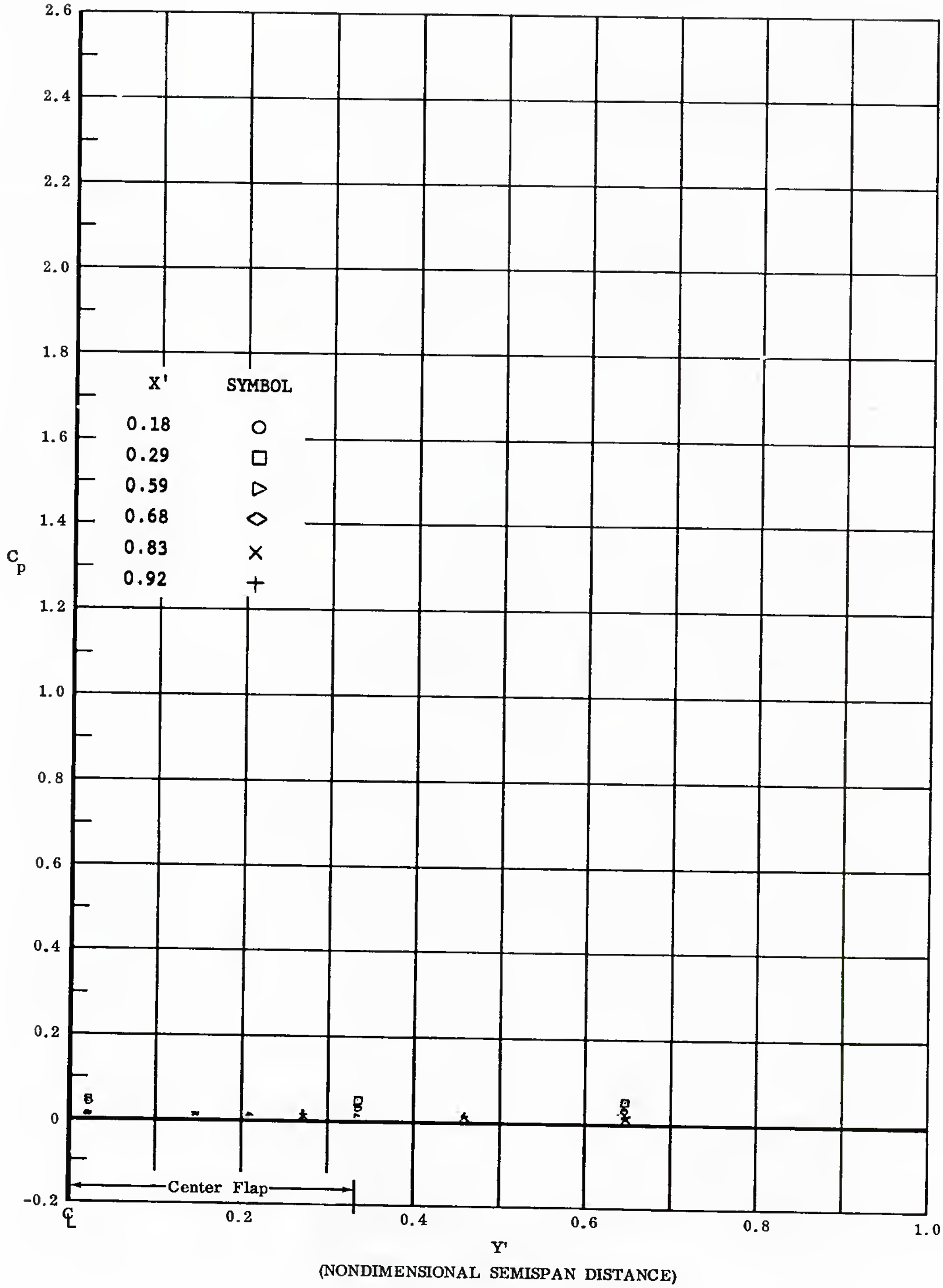


Fig. 23 Spanwise Pressure Distributions; End Plates On, Forward Flap Deflected 15°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

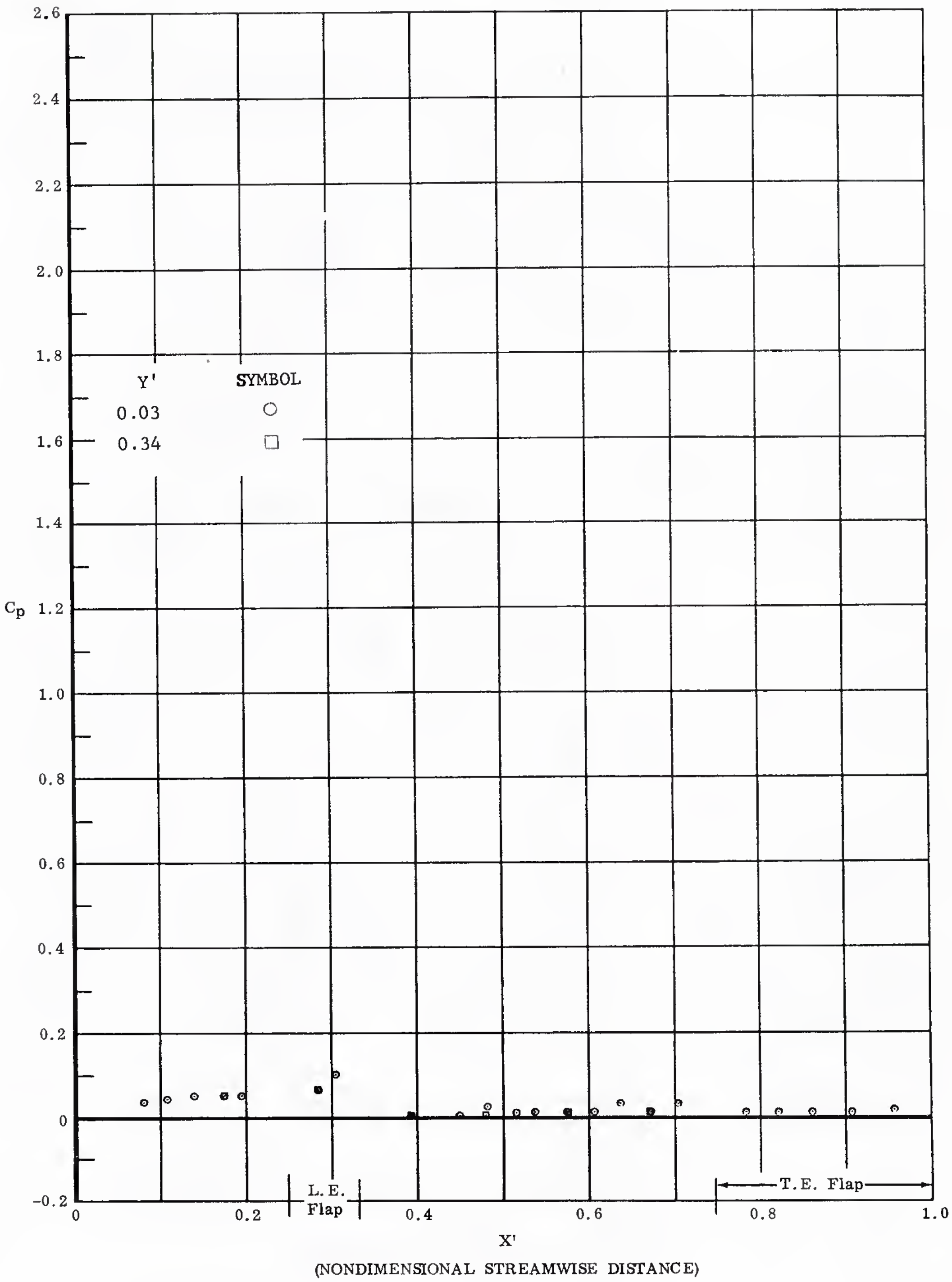


Fig. 24 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

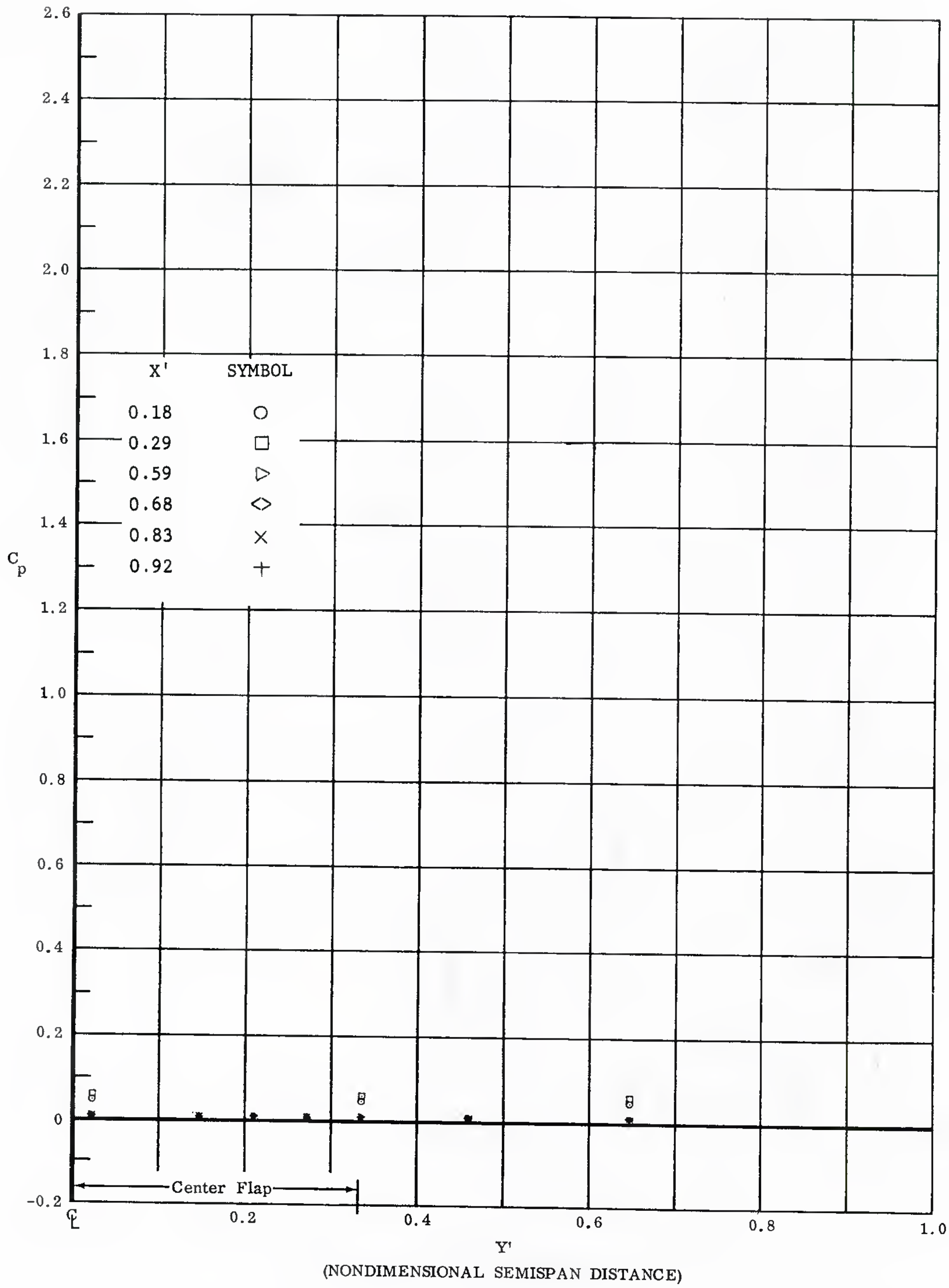


Fig. 24 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

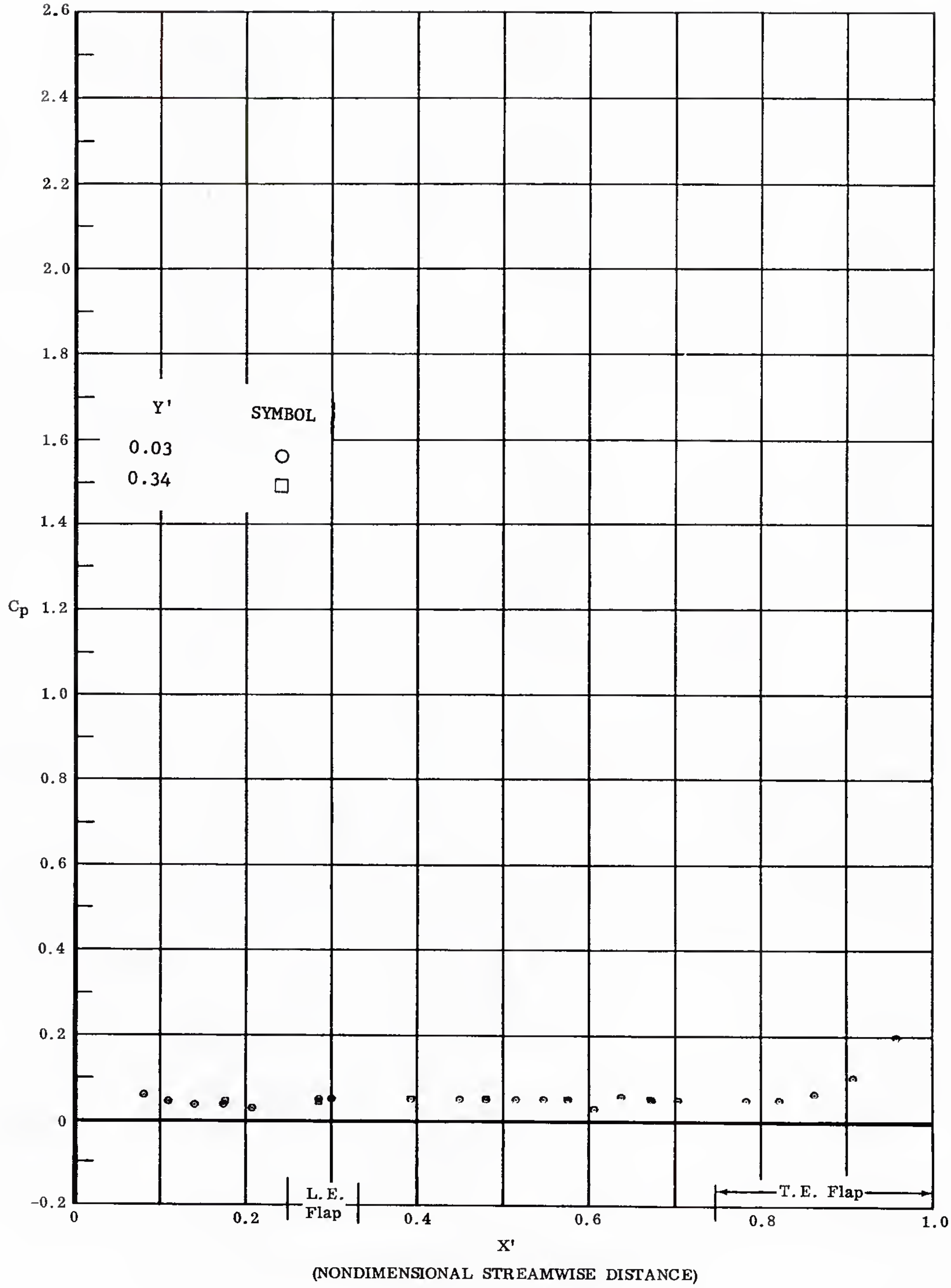


Fig. 25 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

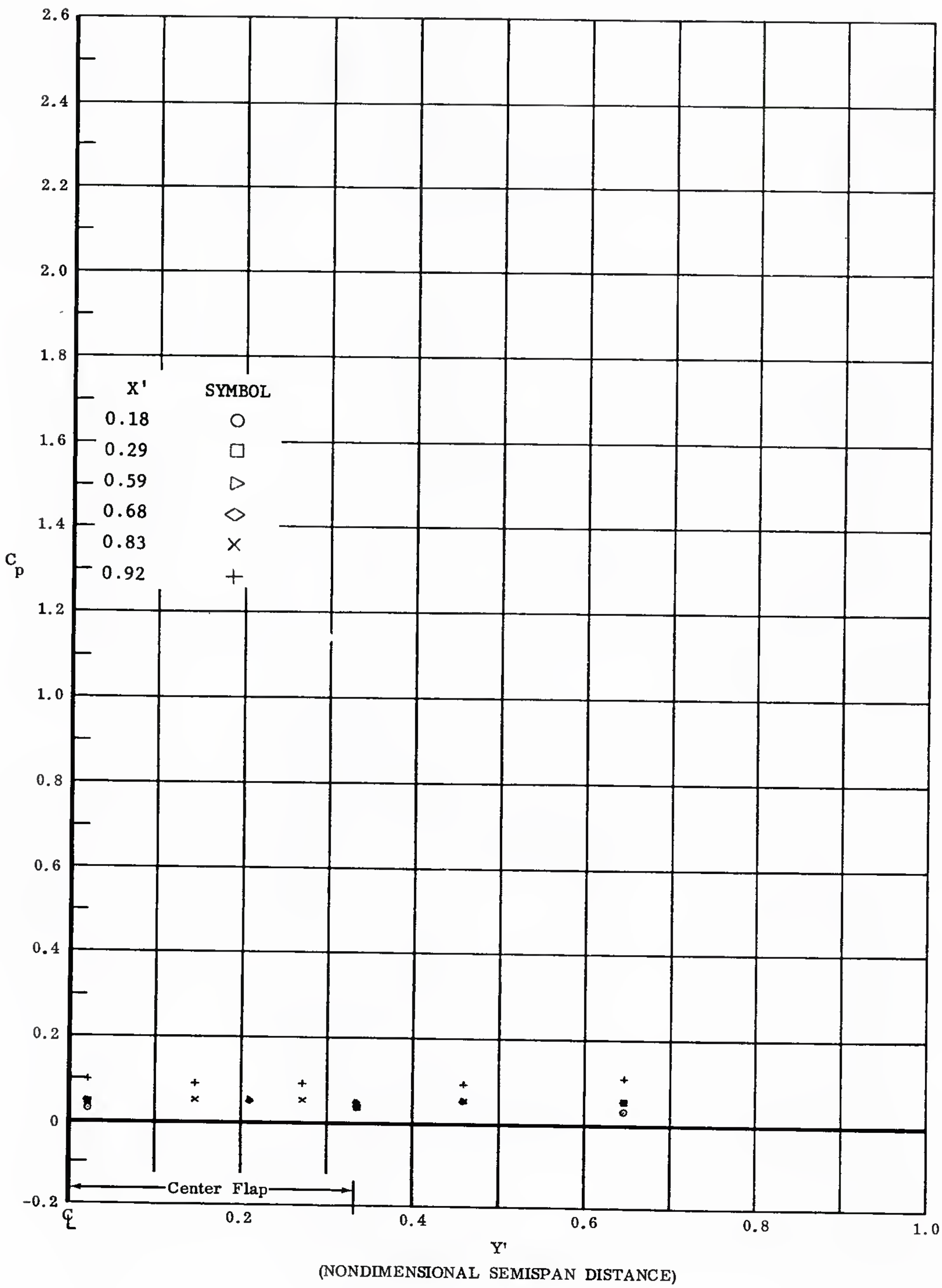


Fig. 25 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_{\infty}/ft = 1,100,000$

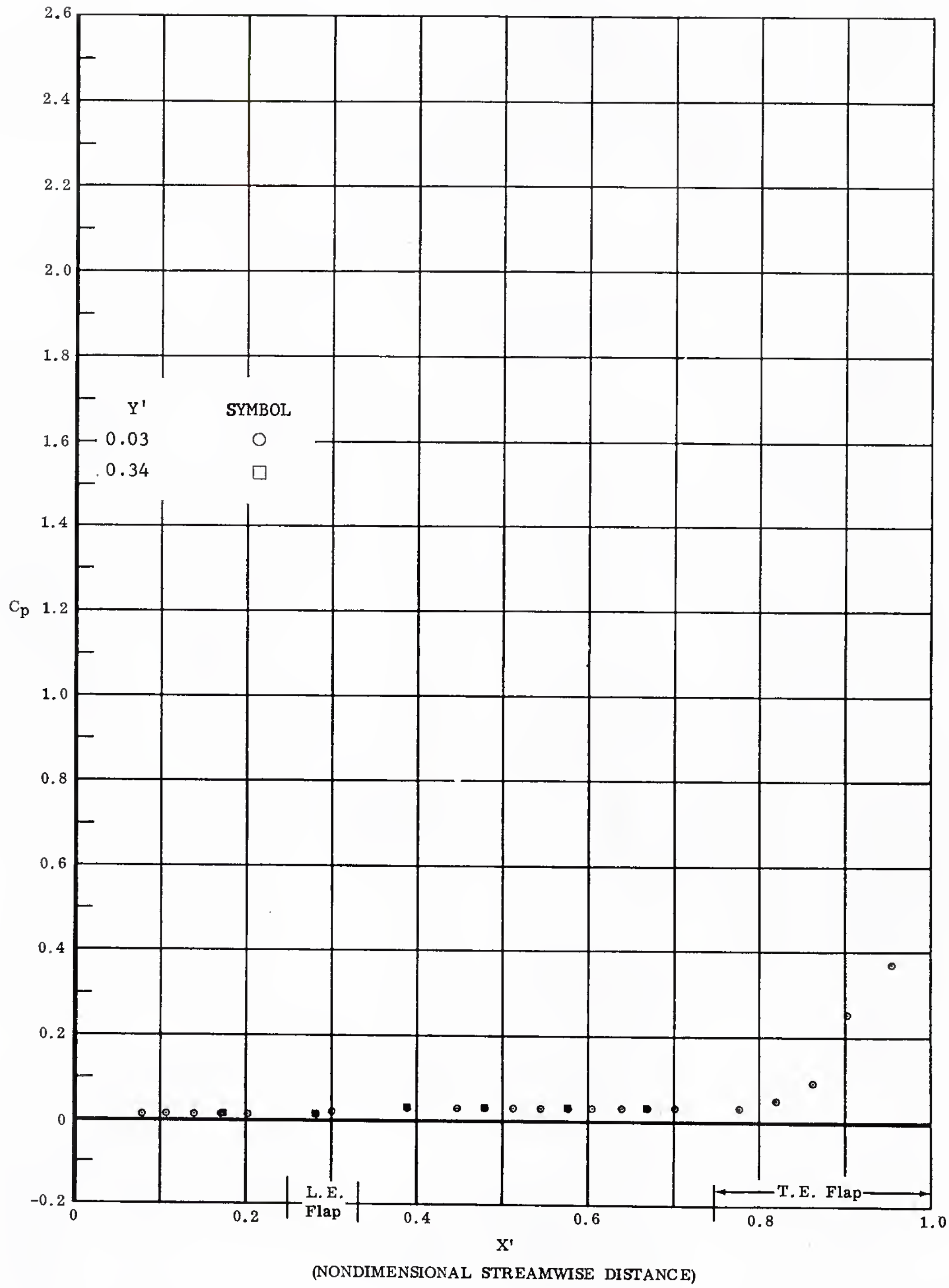


Fig. 26 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

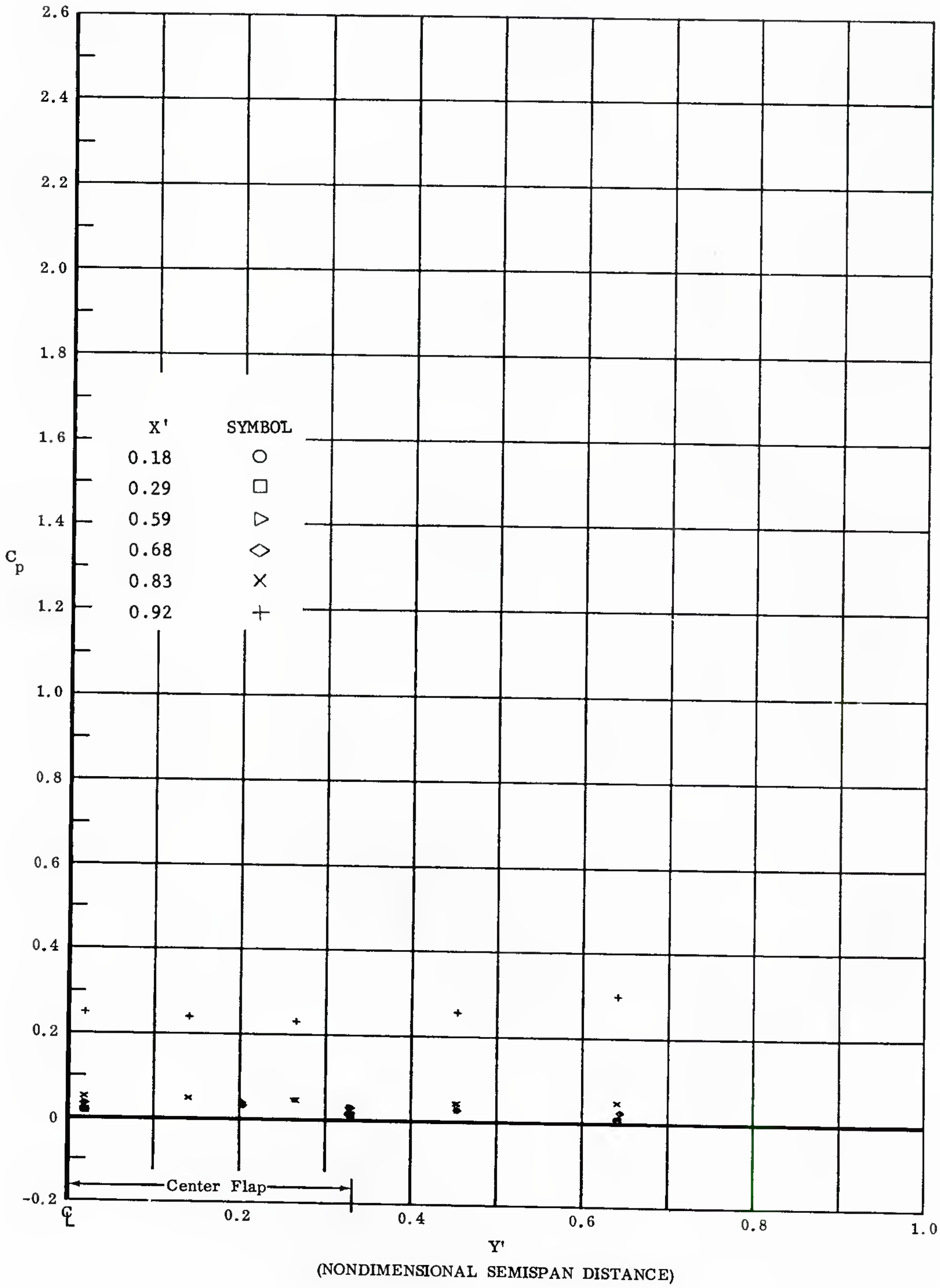


Fig. 26 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

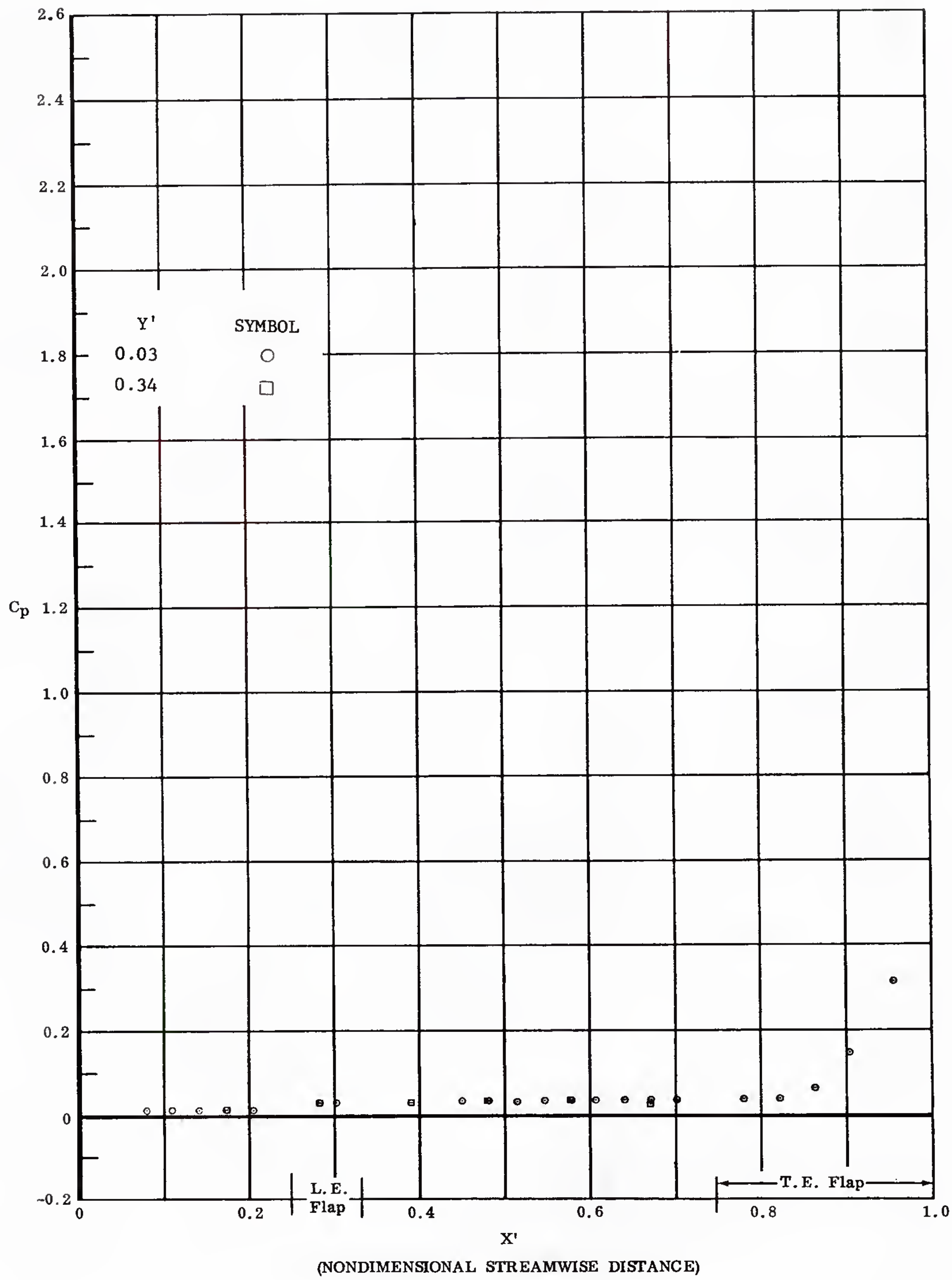


Fig. 27 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

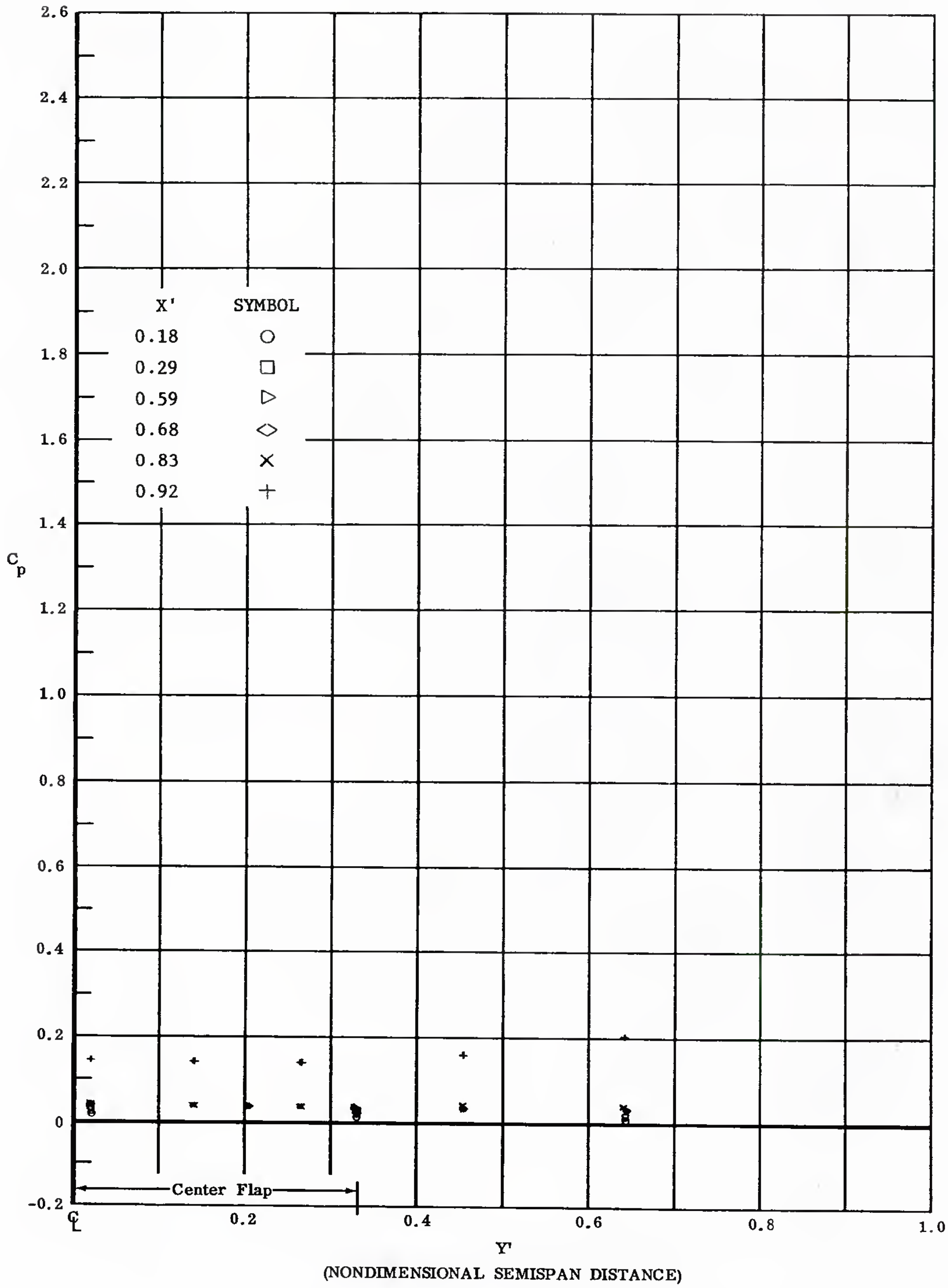


Fig. 27 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 20°, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

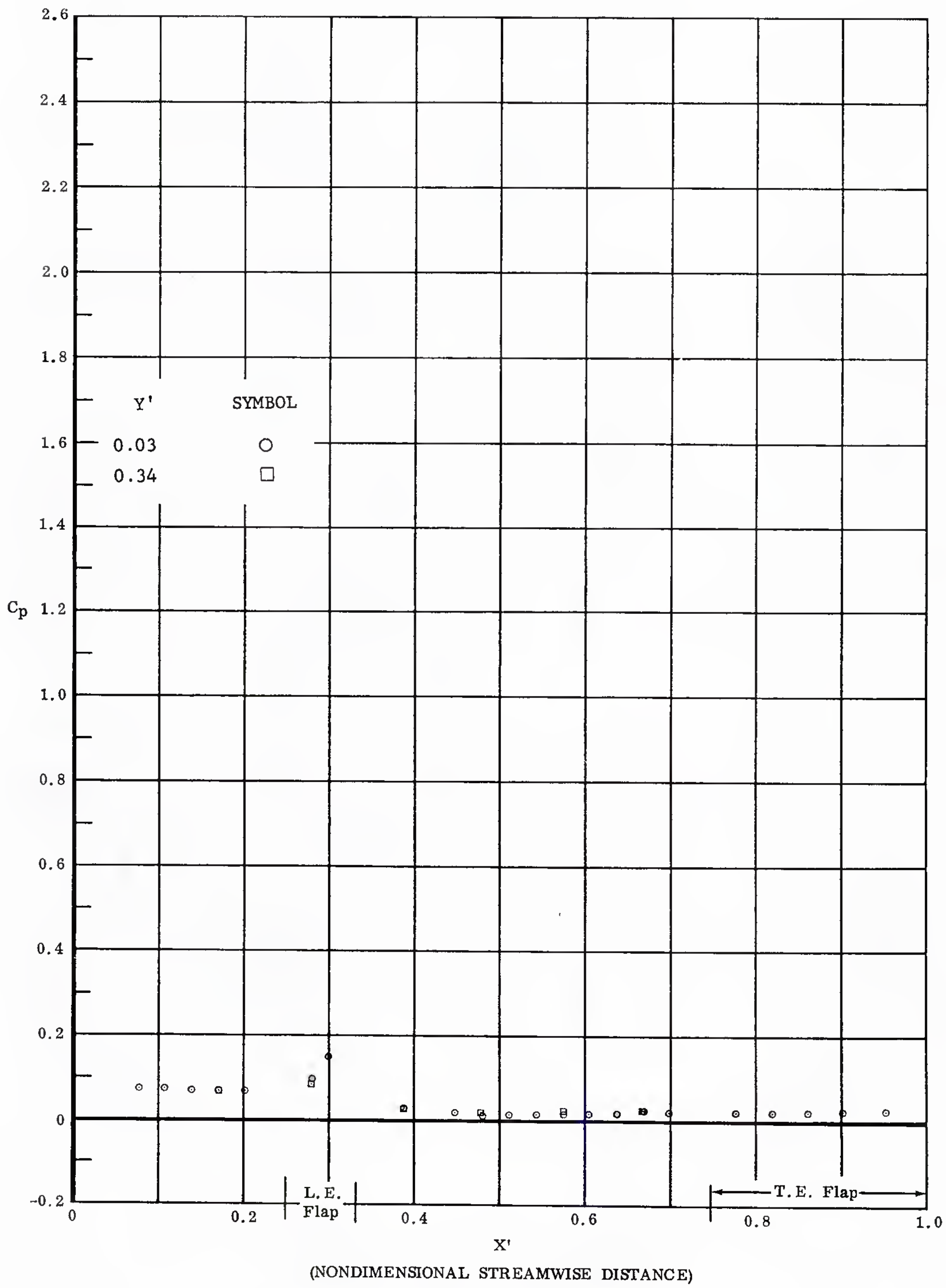


Fig. 28 Streamwise Pressure Distributions; End Plates On, Forward Flap Deflected 30°, $\alpha = 0$, Re_{∞}/ft = 1,100,000

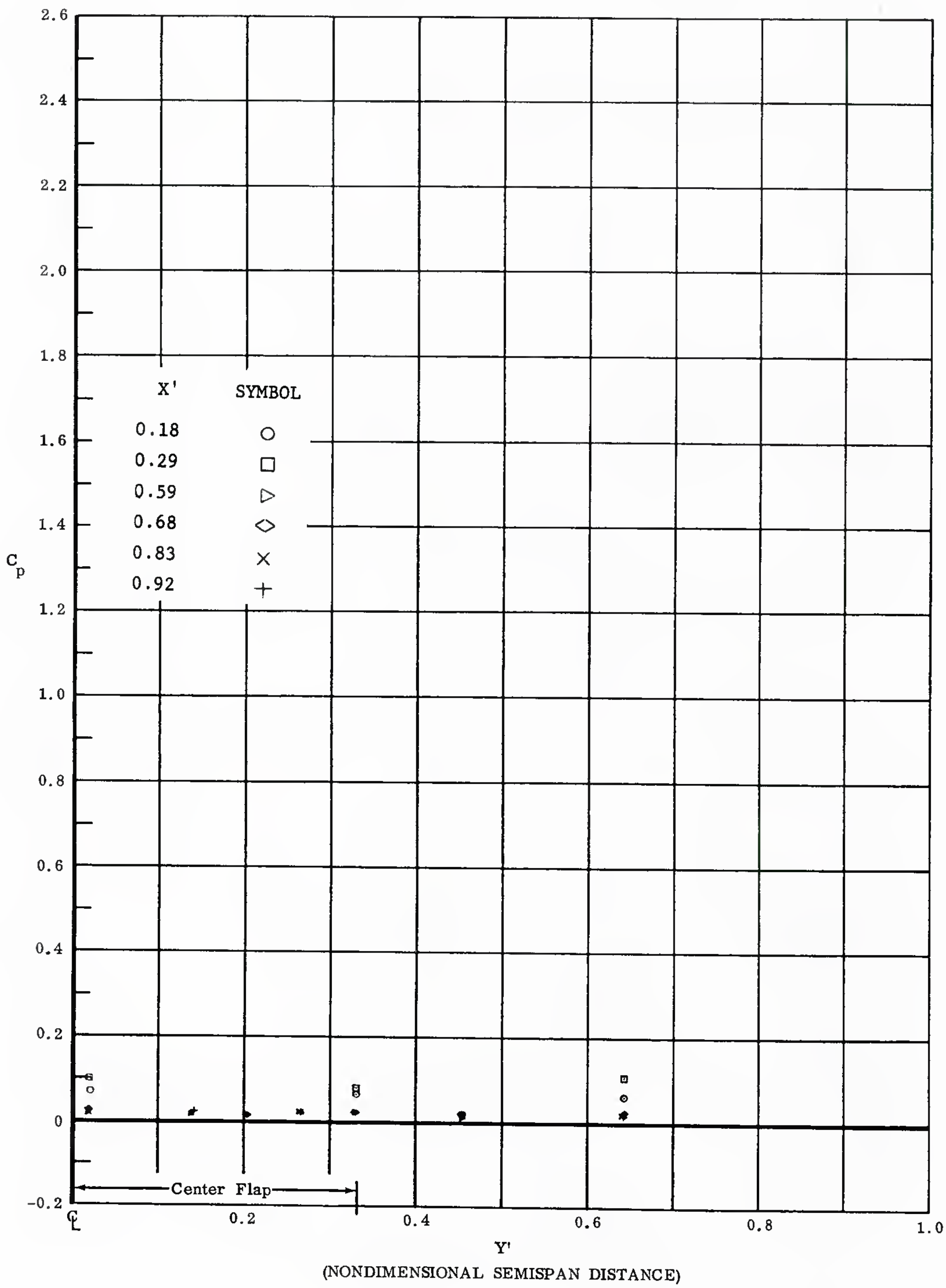


Fig. 28 Spanwise Pressure Distributions; End Plates On, Forward Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

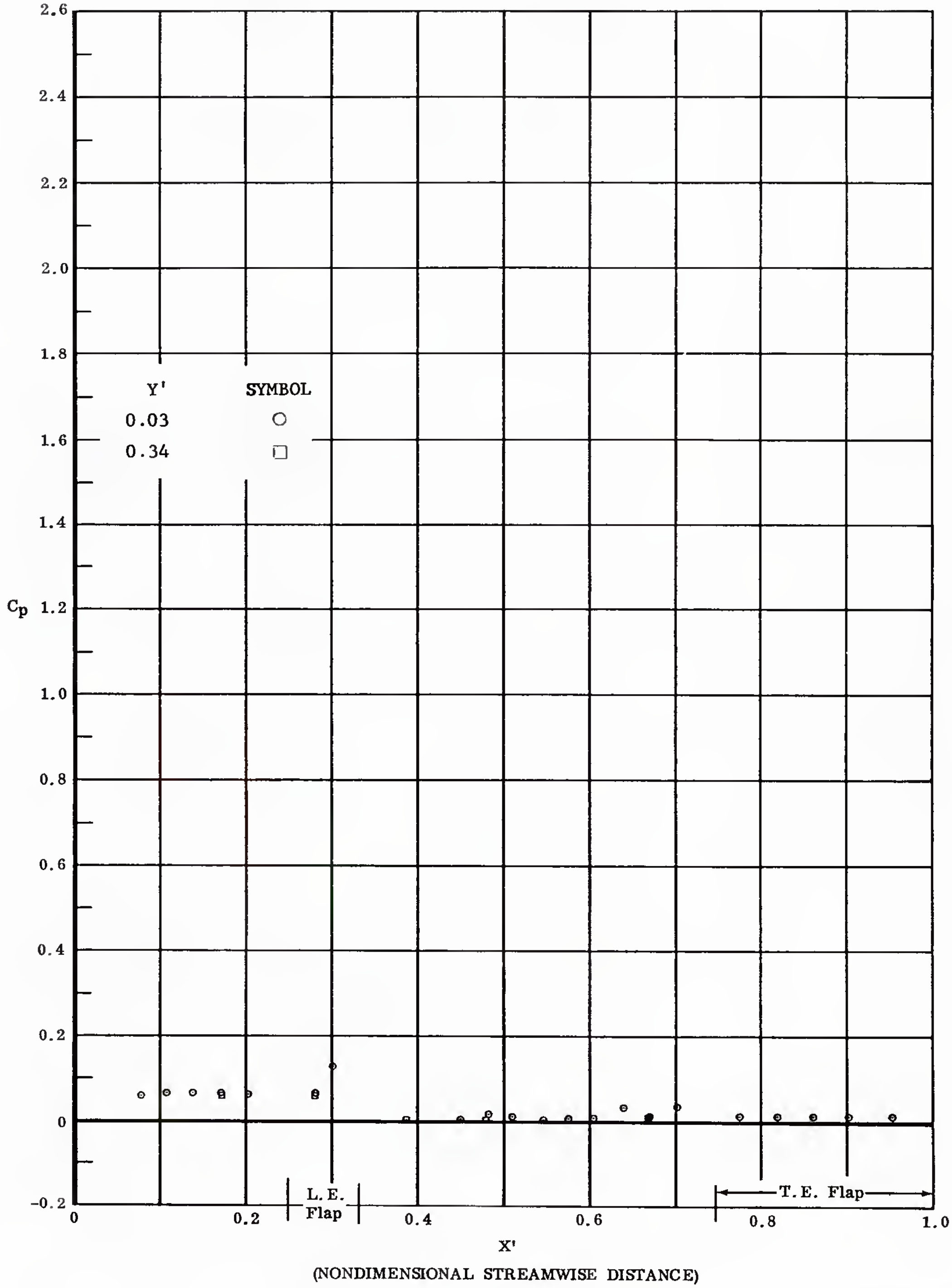


Fig. 29 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, $\alpha = 0$, Re_∞/ft = 3,300,000

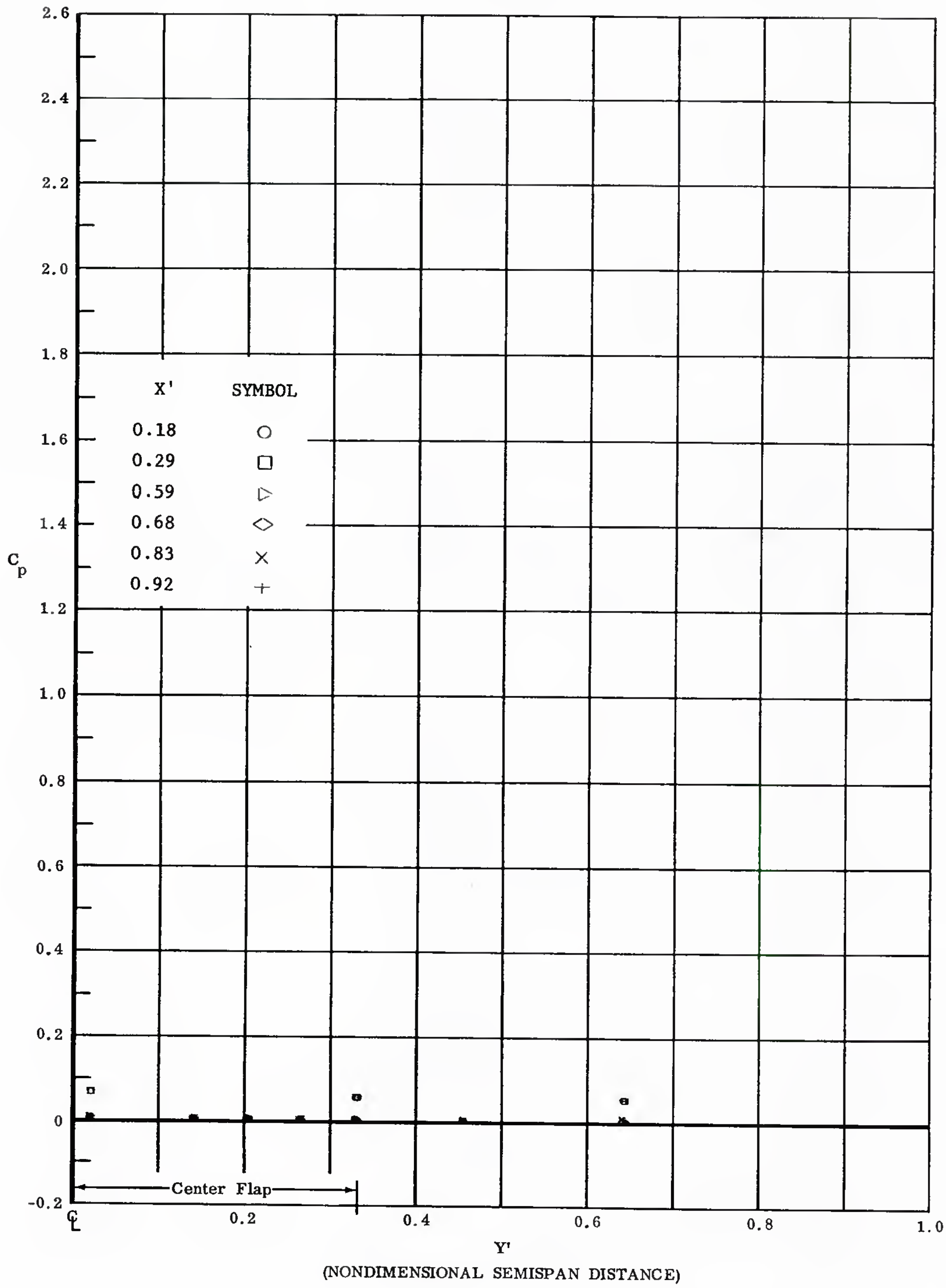


Fig. 29 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

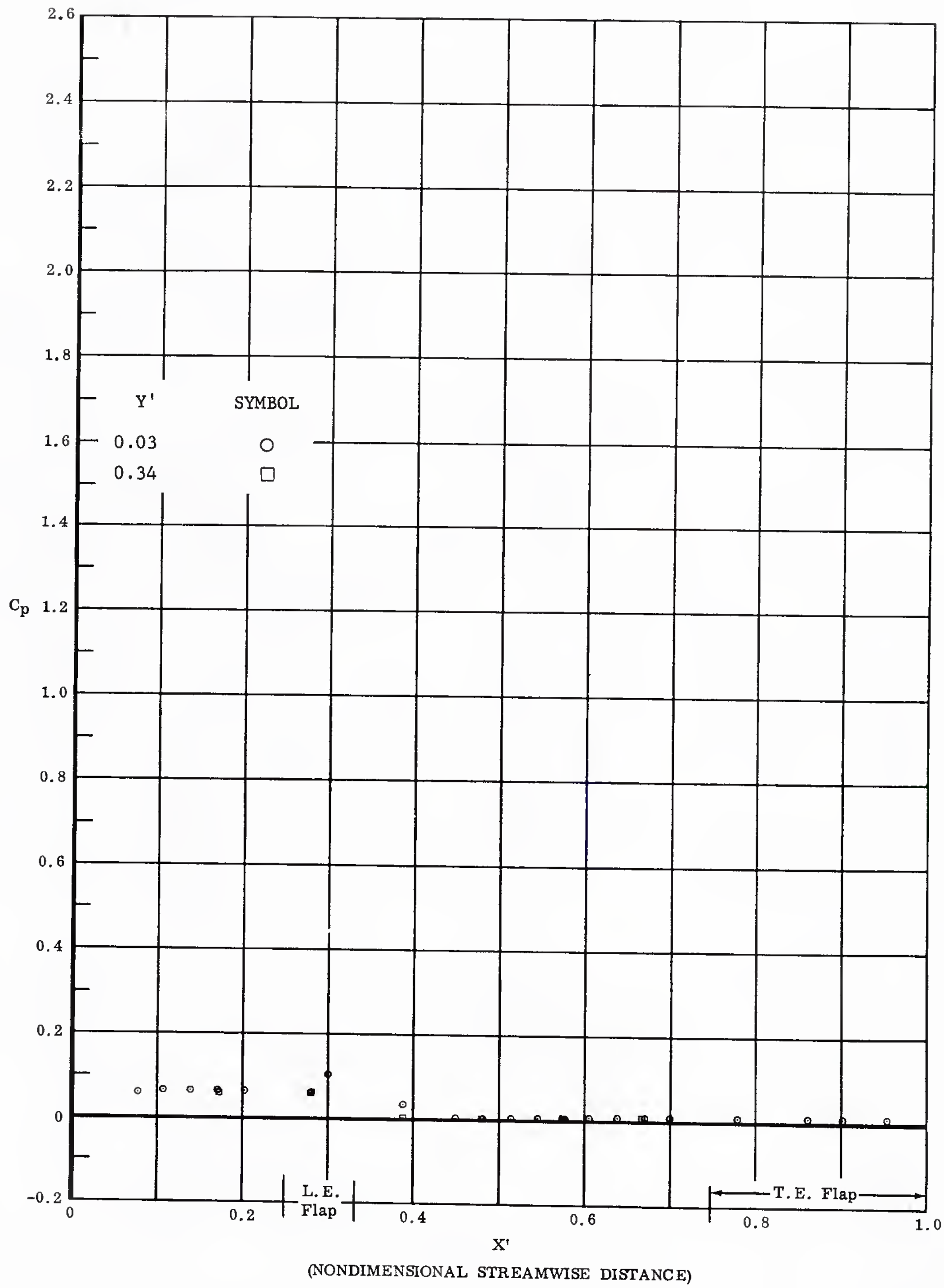


Fig. 30 Streamwise Pressure Distributions; End Plates On, Forward Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

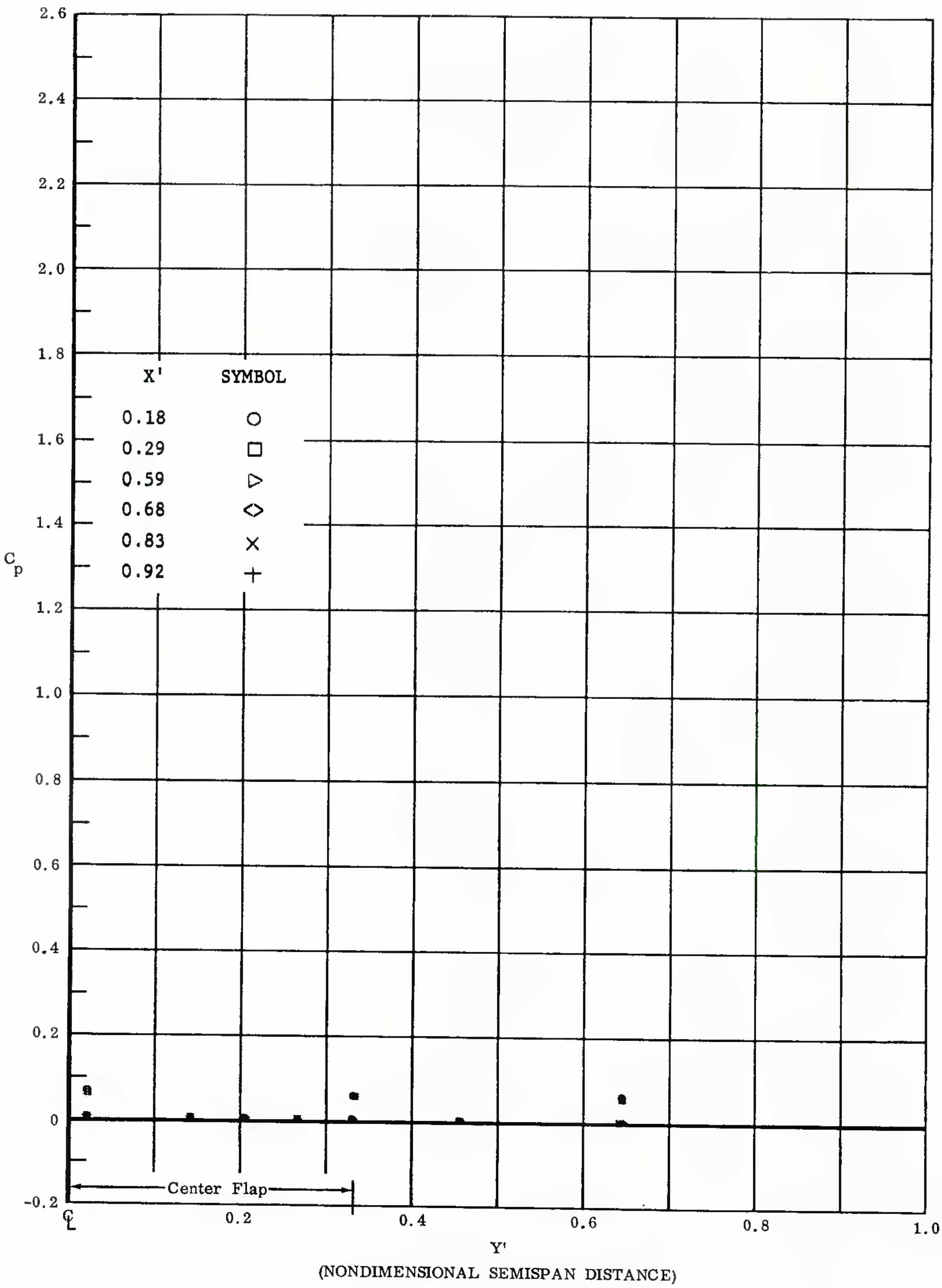


Fig. 30 Spanwise Pressure Distributions; End Plates On, Forward Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

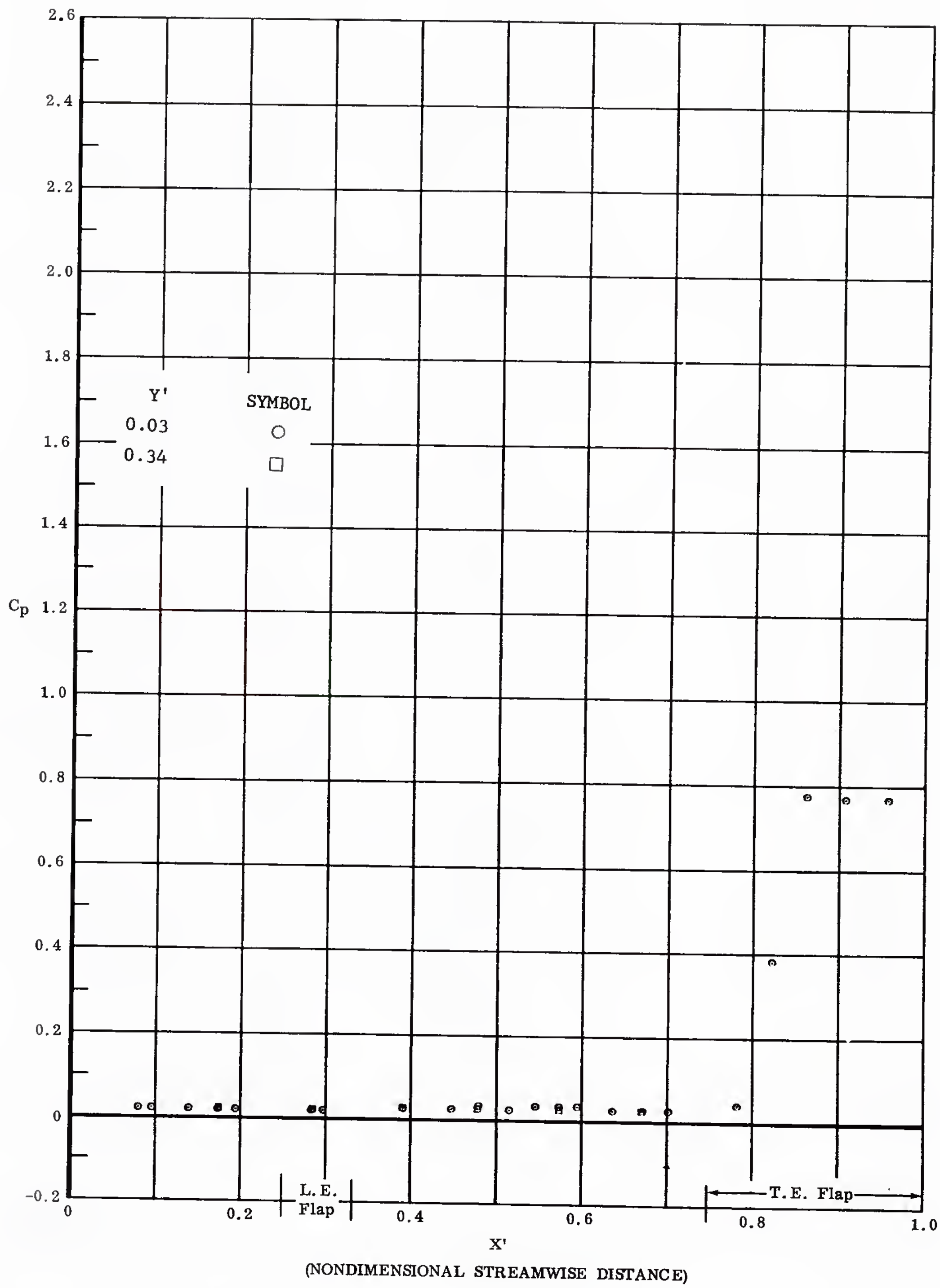


Fig. 31 Streamwise Pressure Distributions; End Plates Off, Aft Center Flap Deflected 30°, $\alpha = 0$, $Re_{\infty}/ft = 3{,}300{,}000$

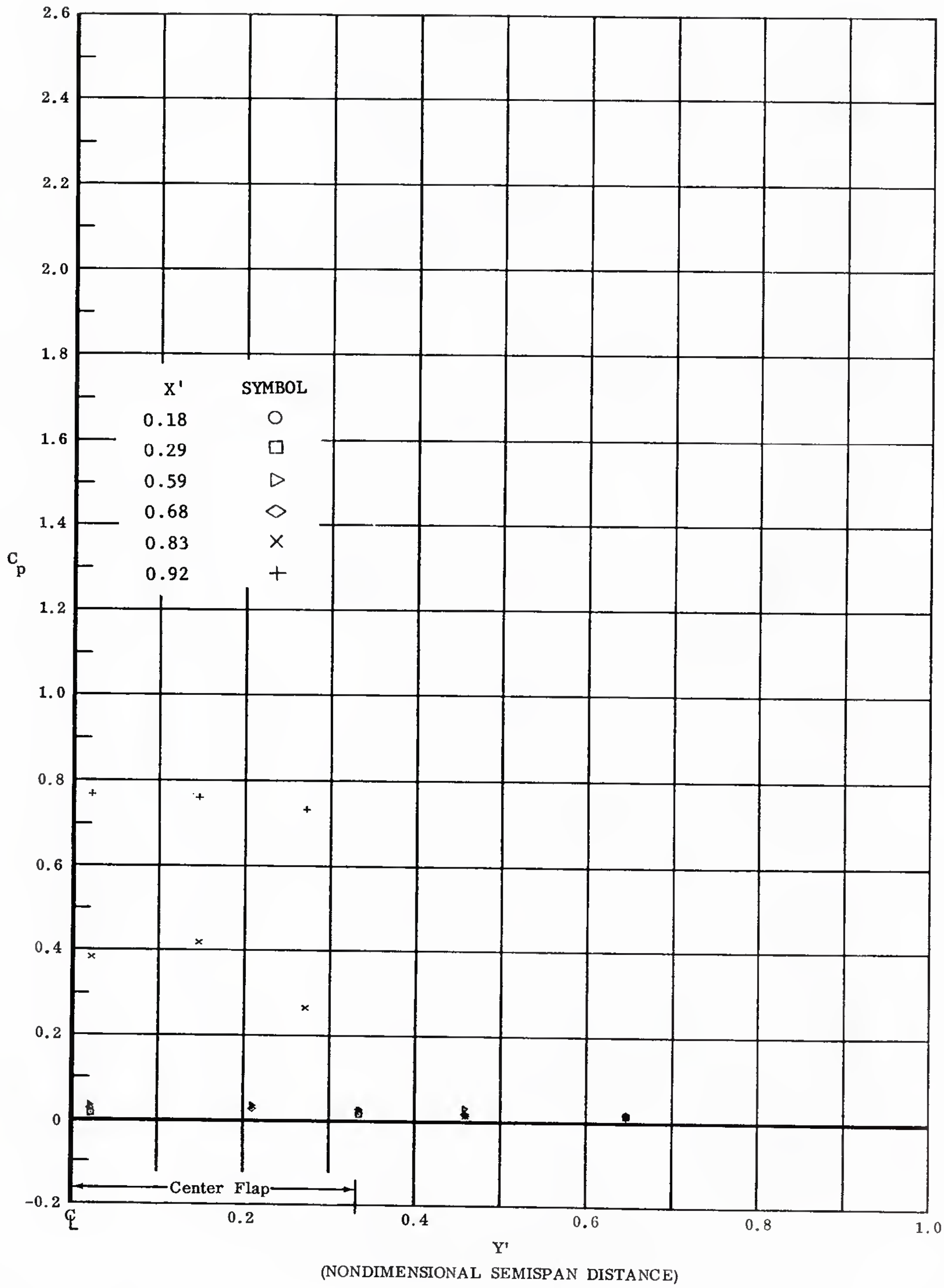


Fig. 31 Spanwise Pressure Distributions; End Plates Off, Aft Center Flap Deflected 30°, $\alpha = 0$, Re_∞/ft = 3,300,000

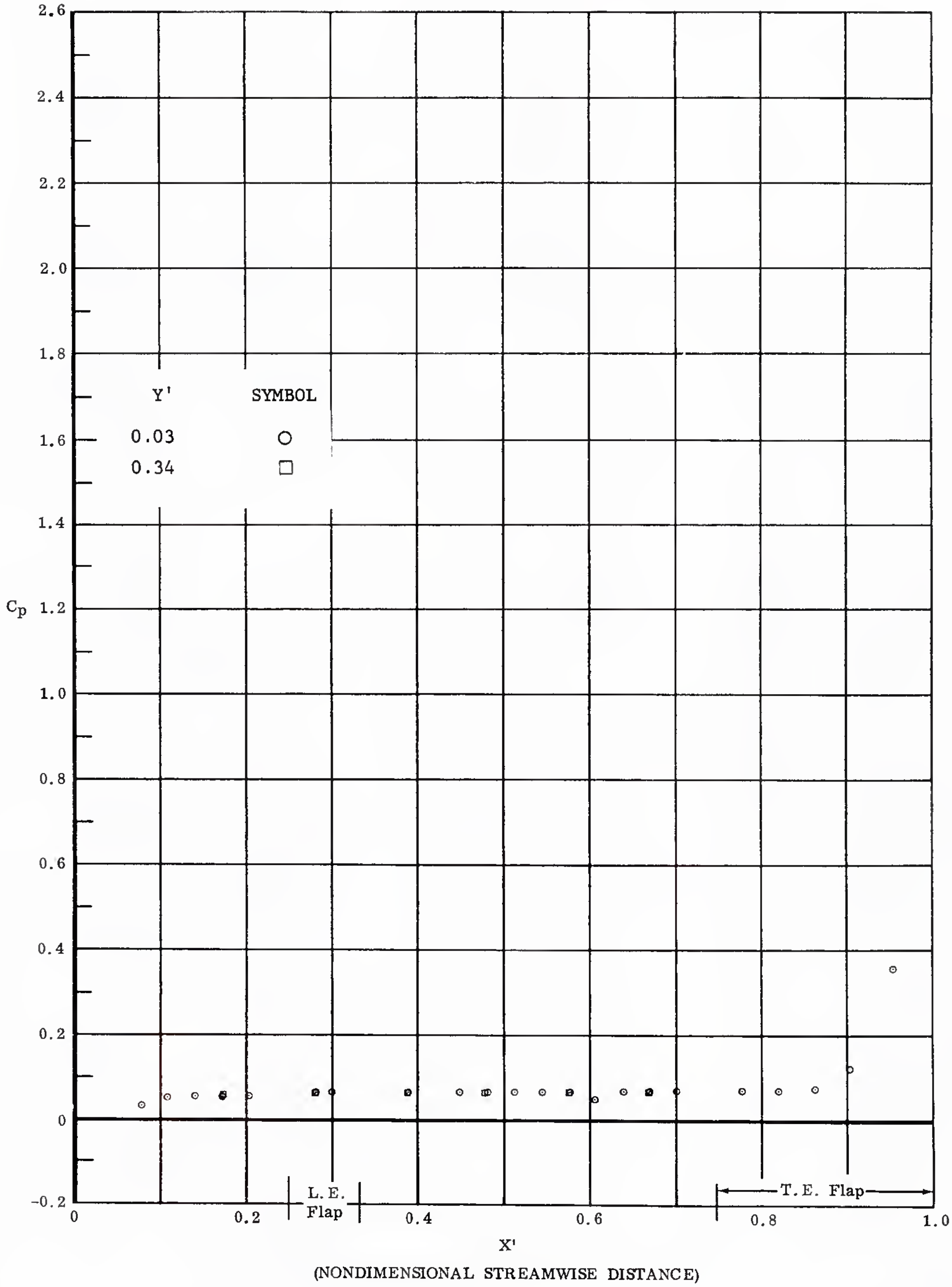


Fig. 32 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

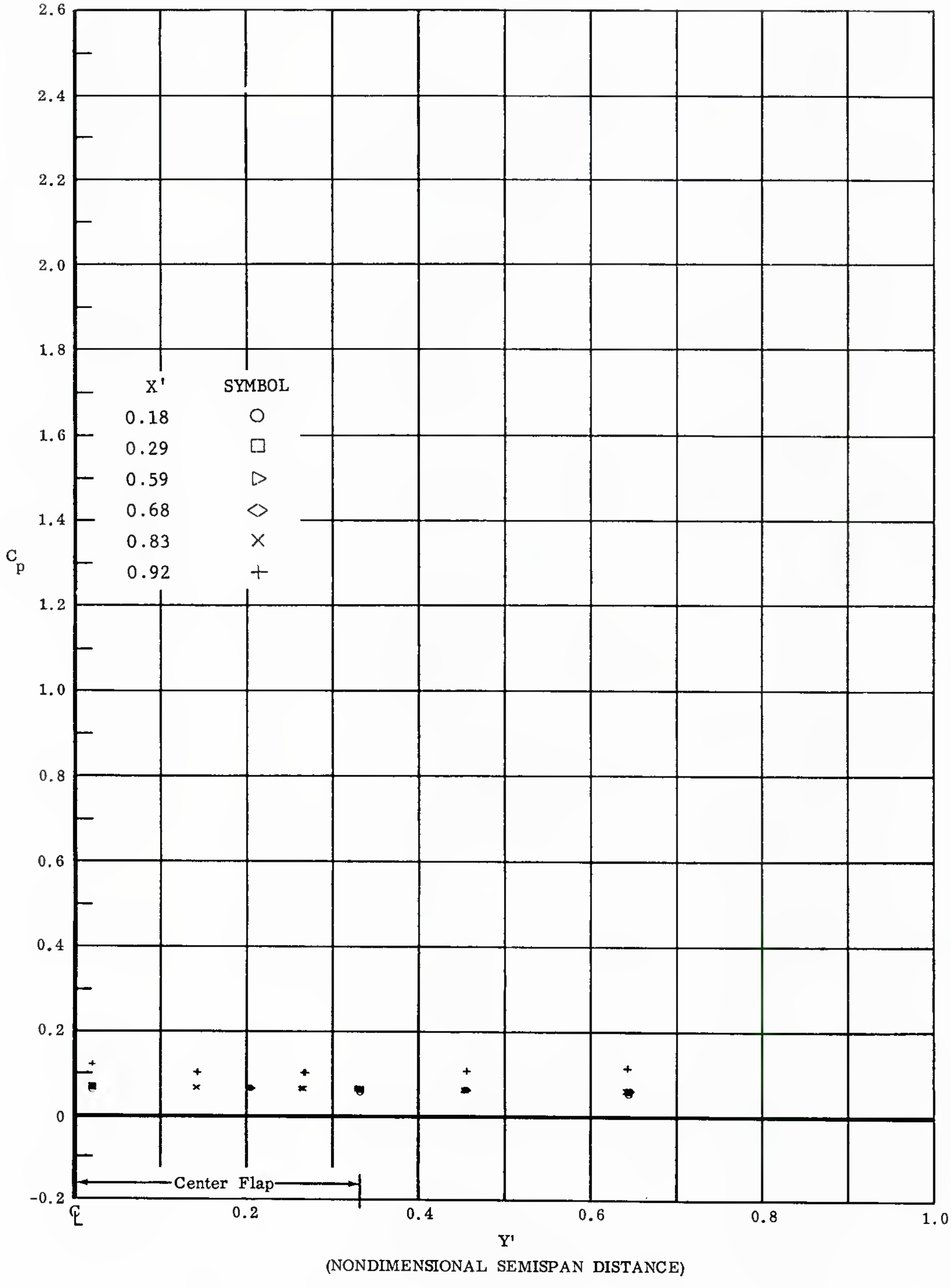


Fig. 32 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

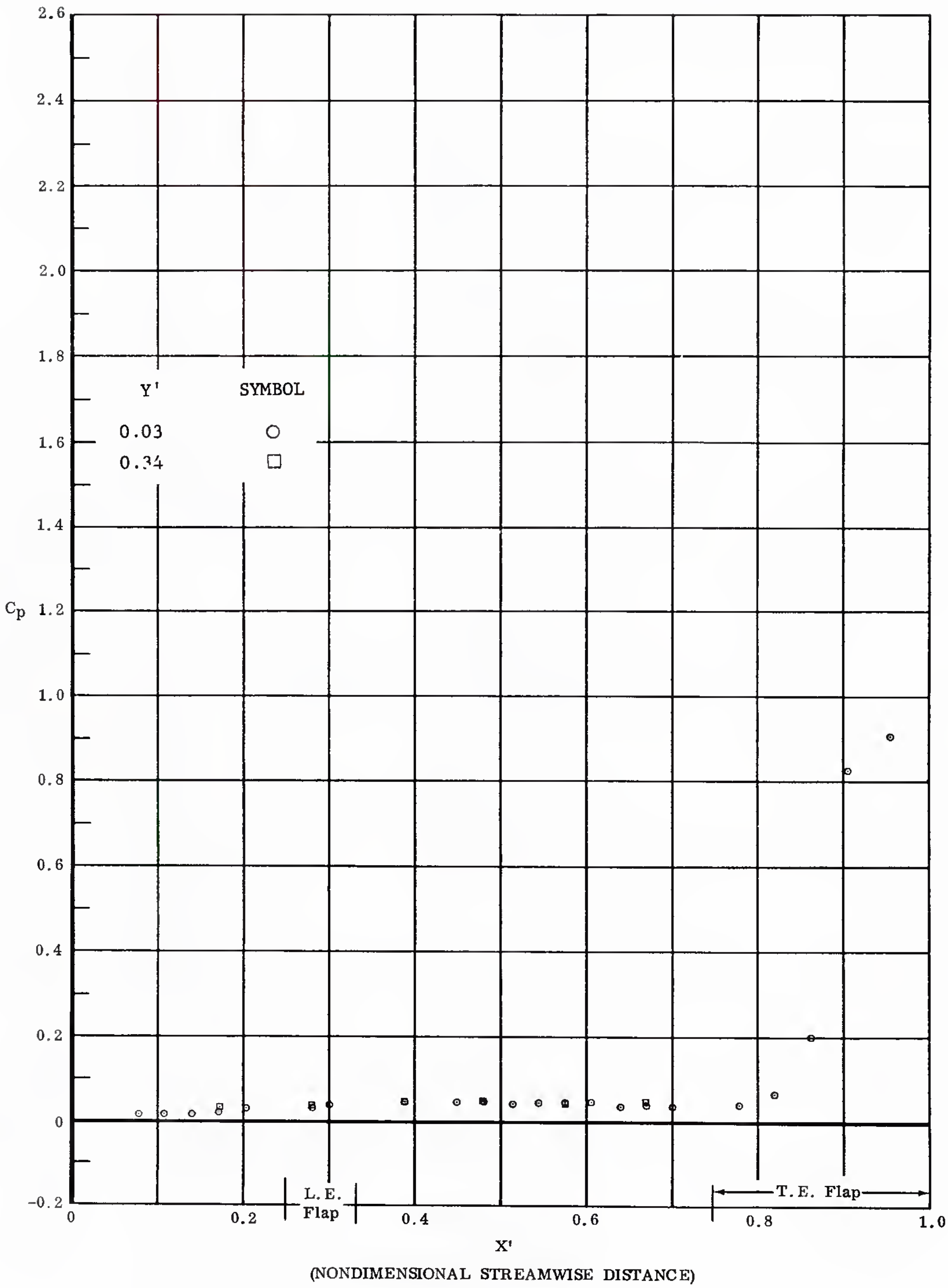


Fig. 33 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 2{,}200{,}000$

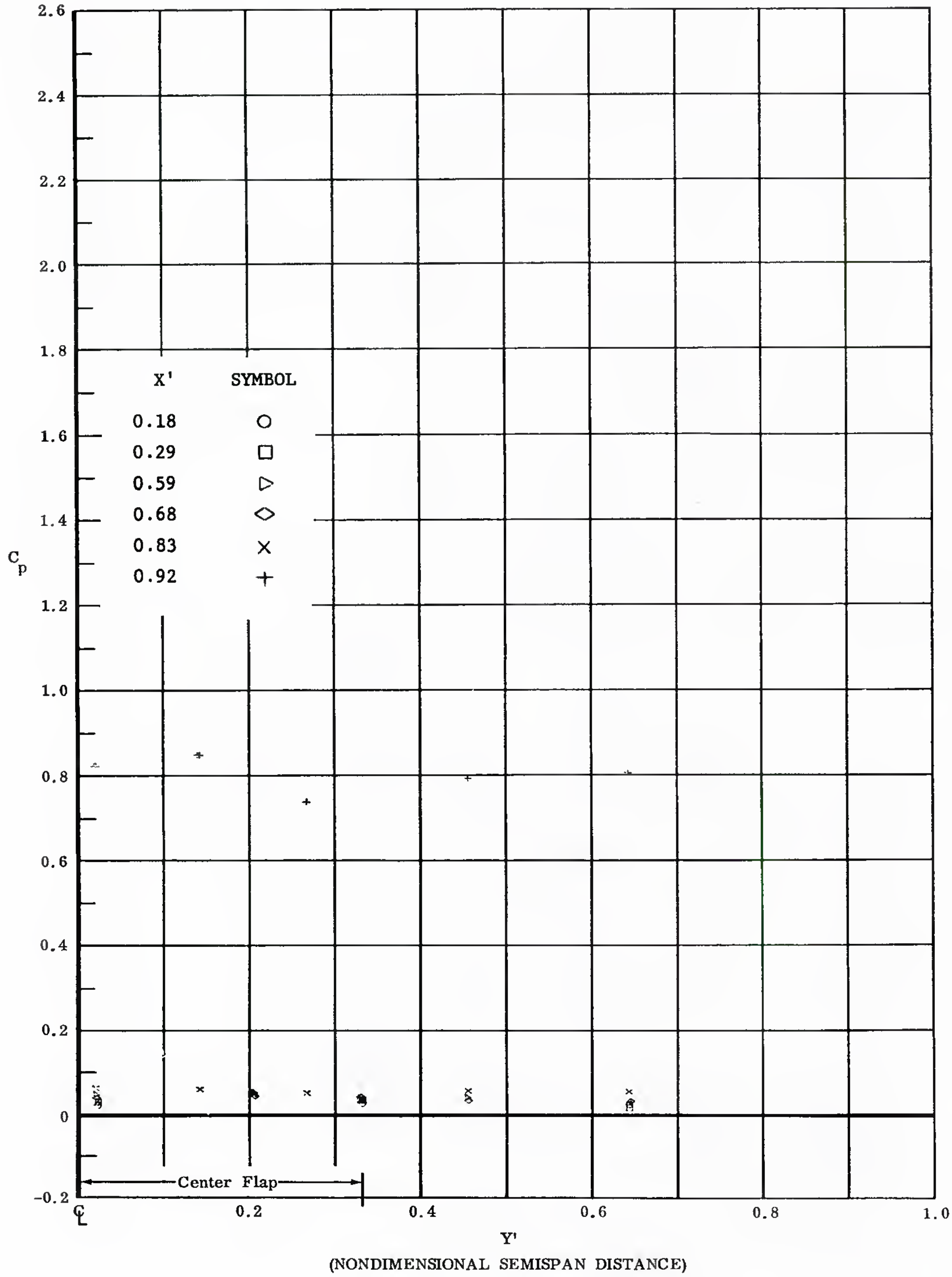


Fig. 33 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $R_{e_\infty}/ft = 2,200,000$

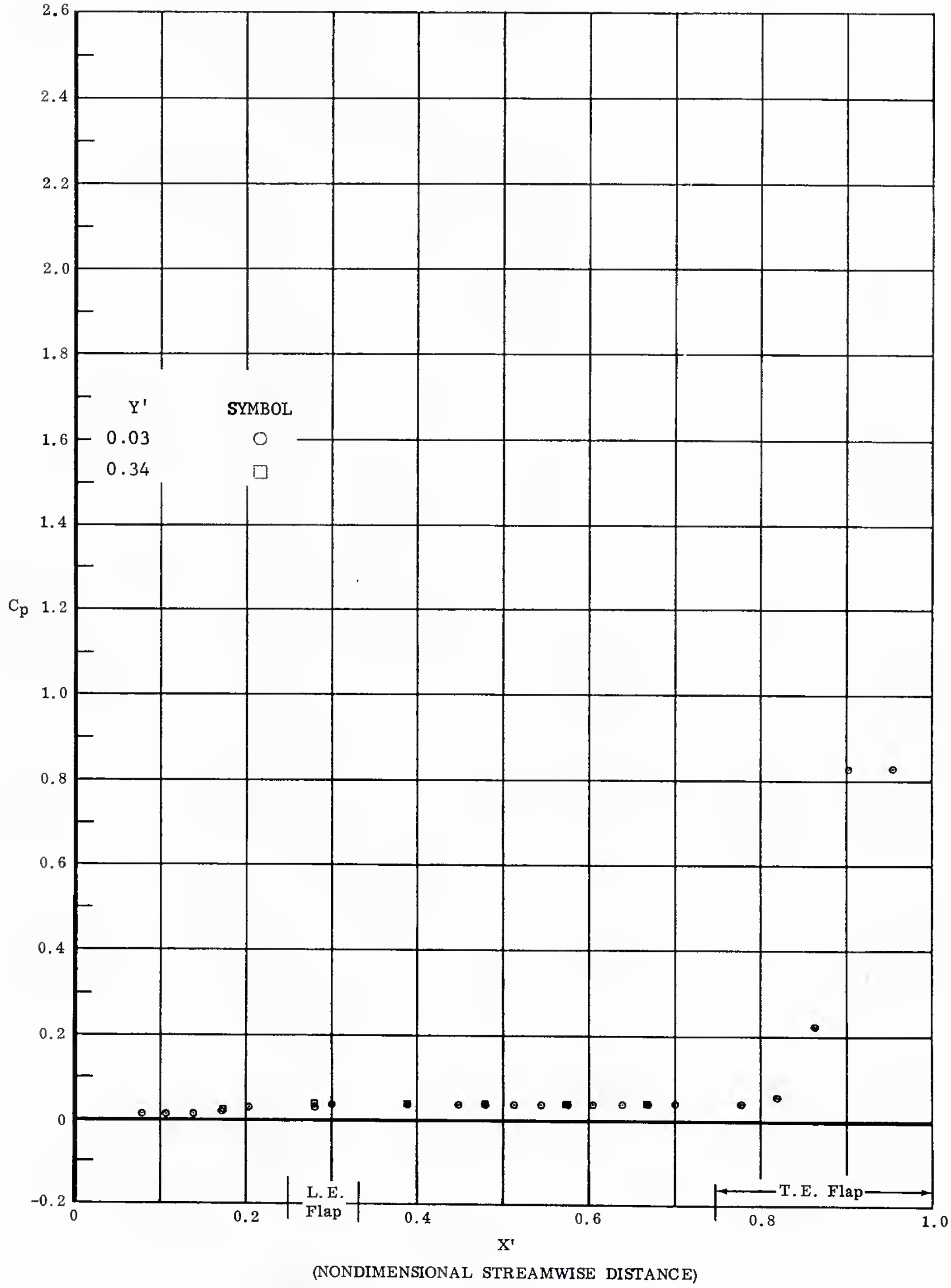


Fig. 34 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

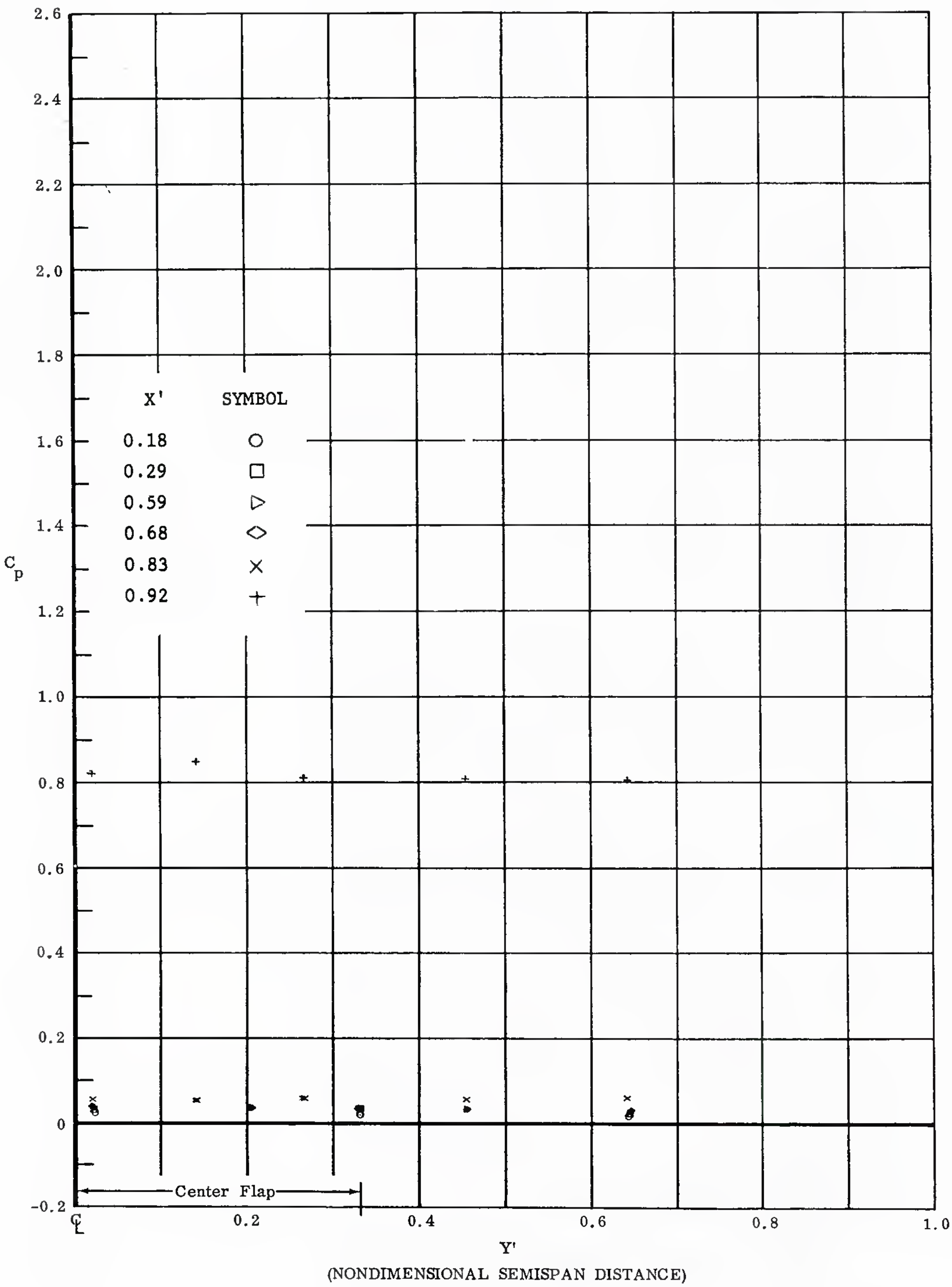


Fig. 34 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

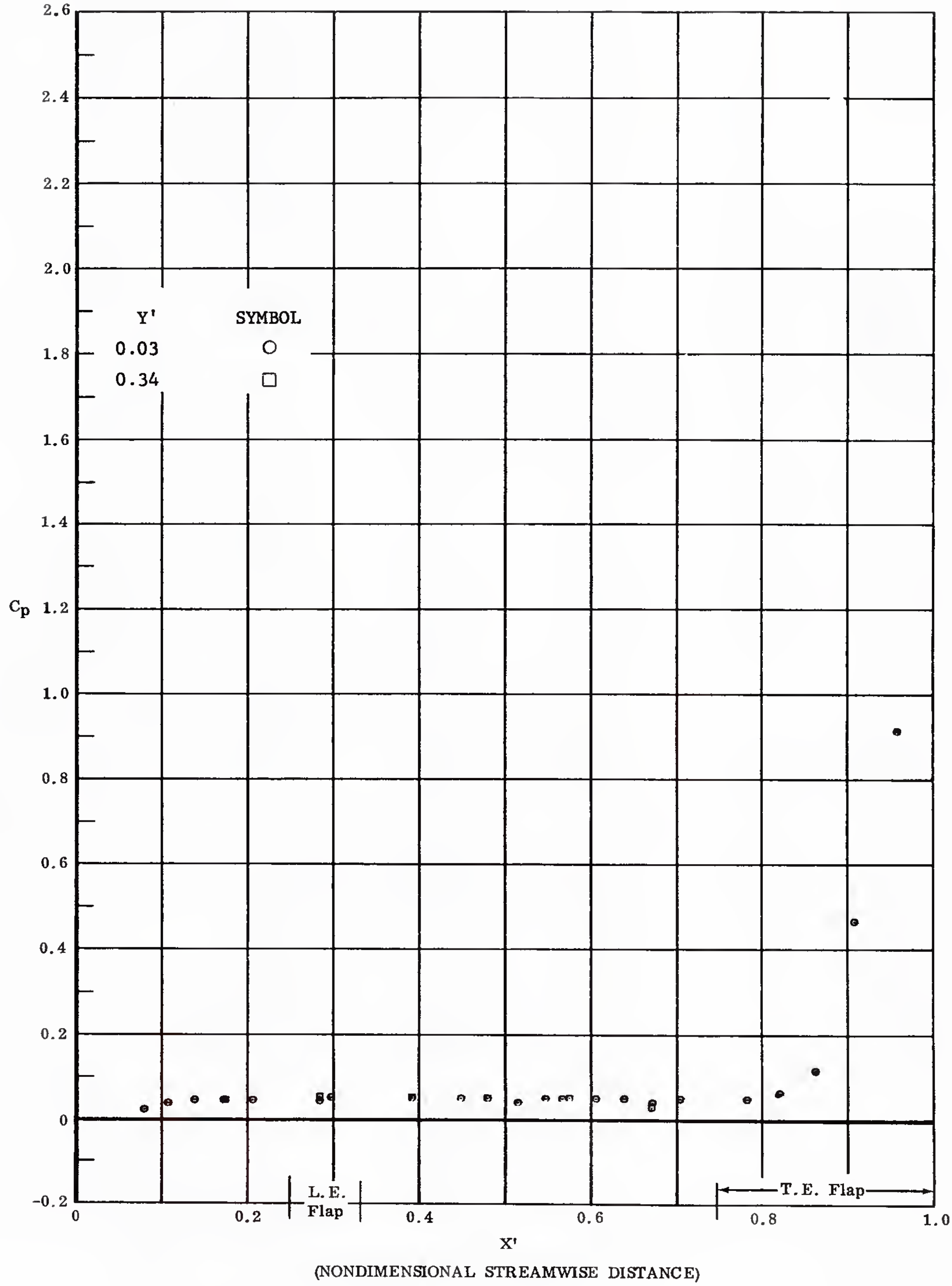


Fig. 35 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

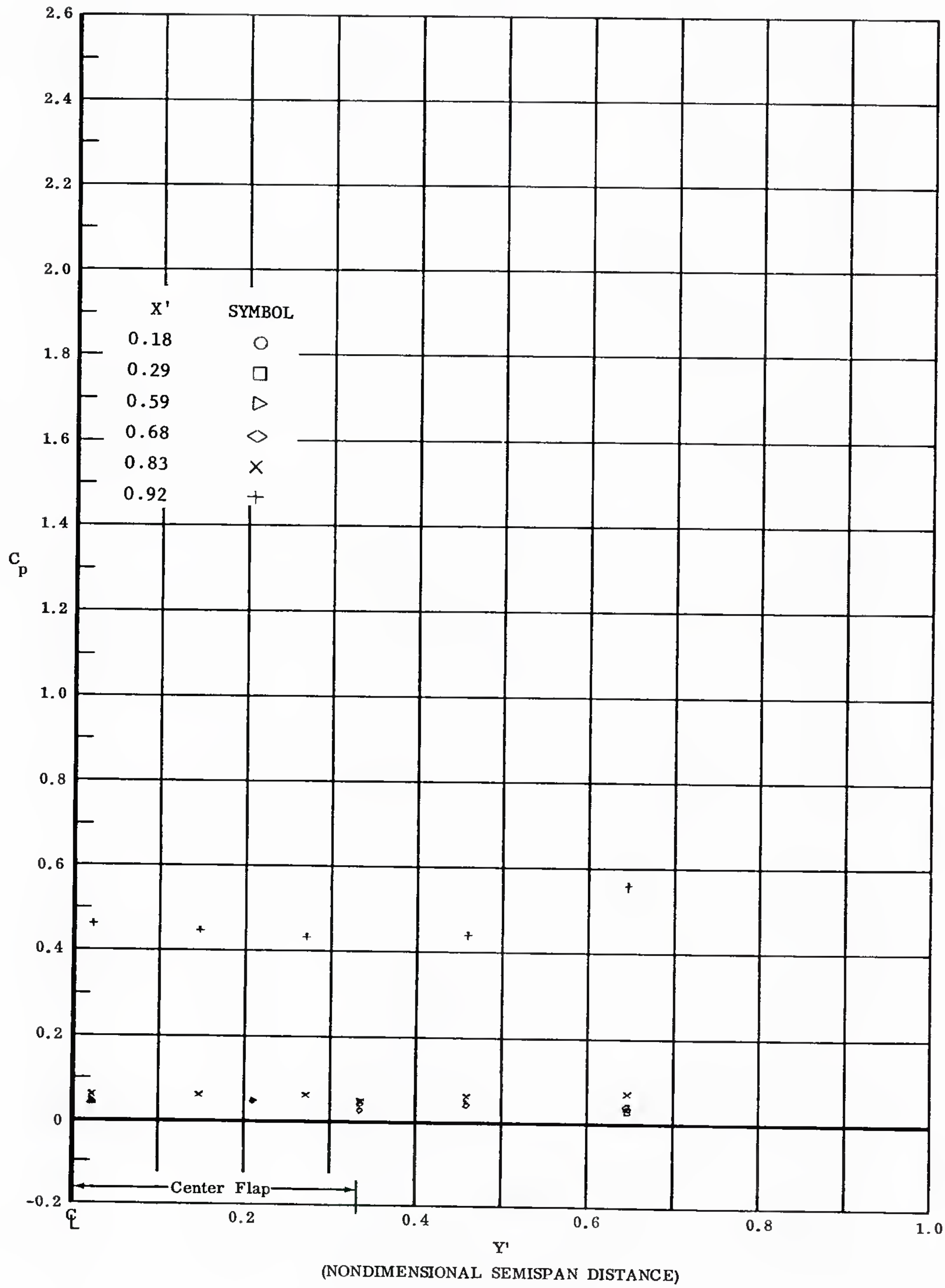


Fig. 35 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

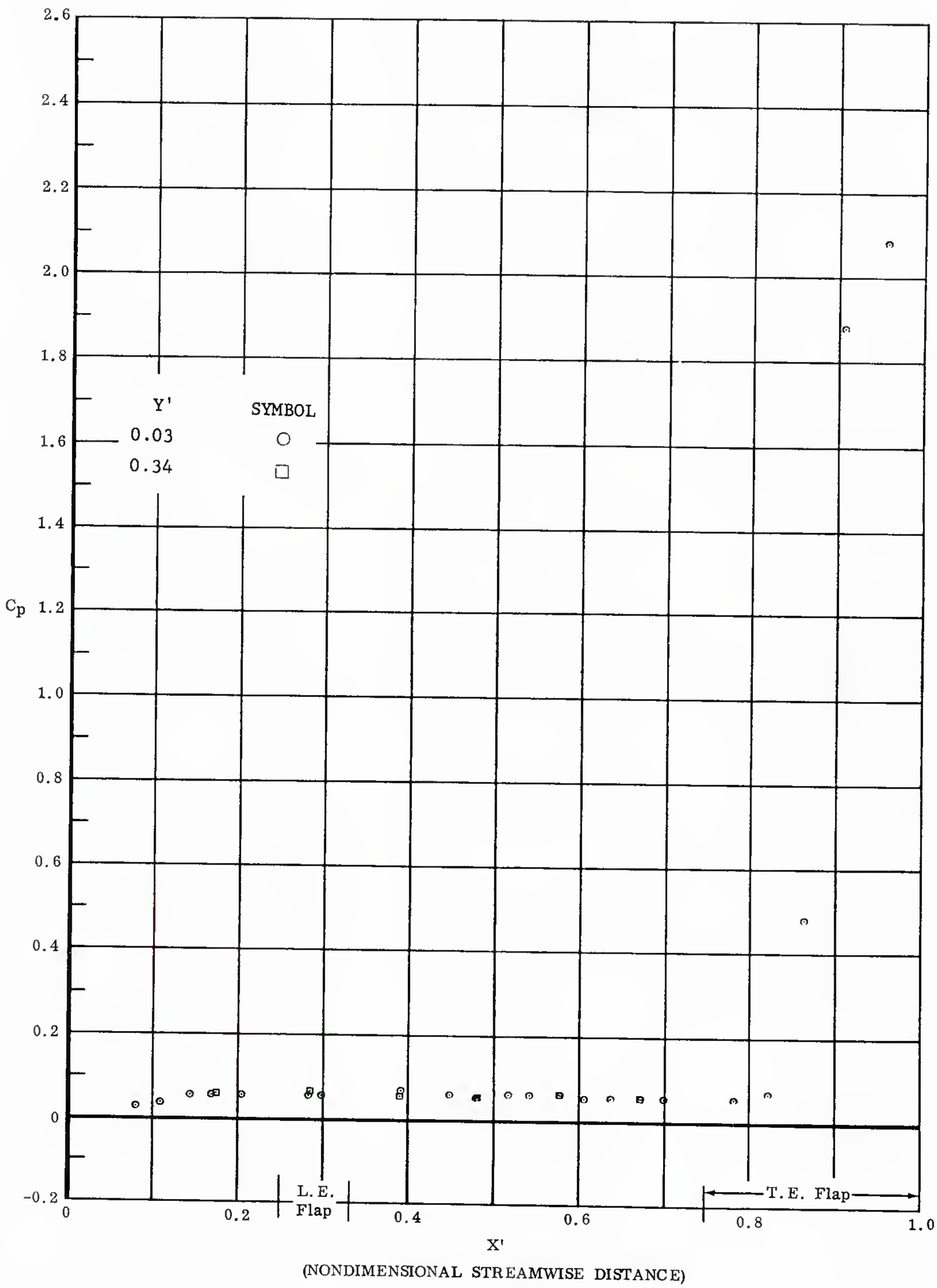


Fig. 36 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°*, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

*See note in Table II, pages 6 and 7.

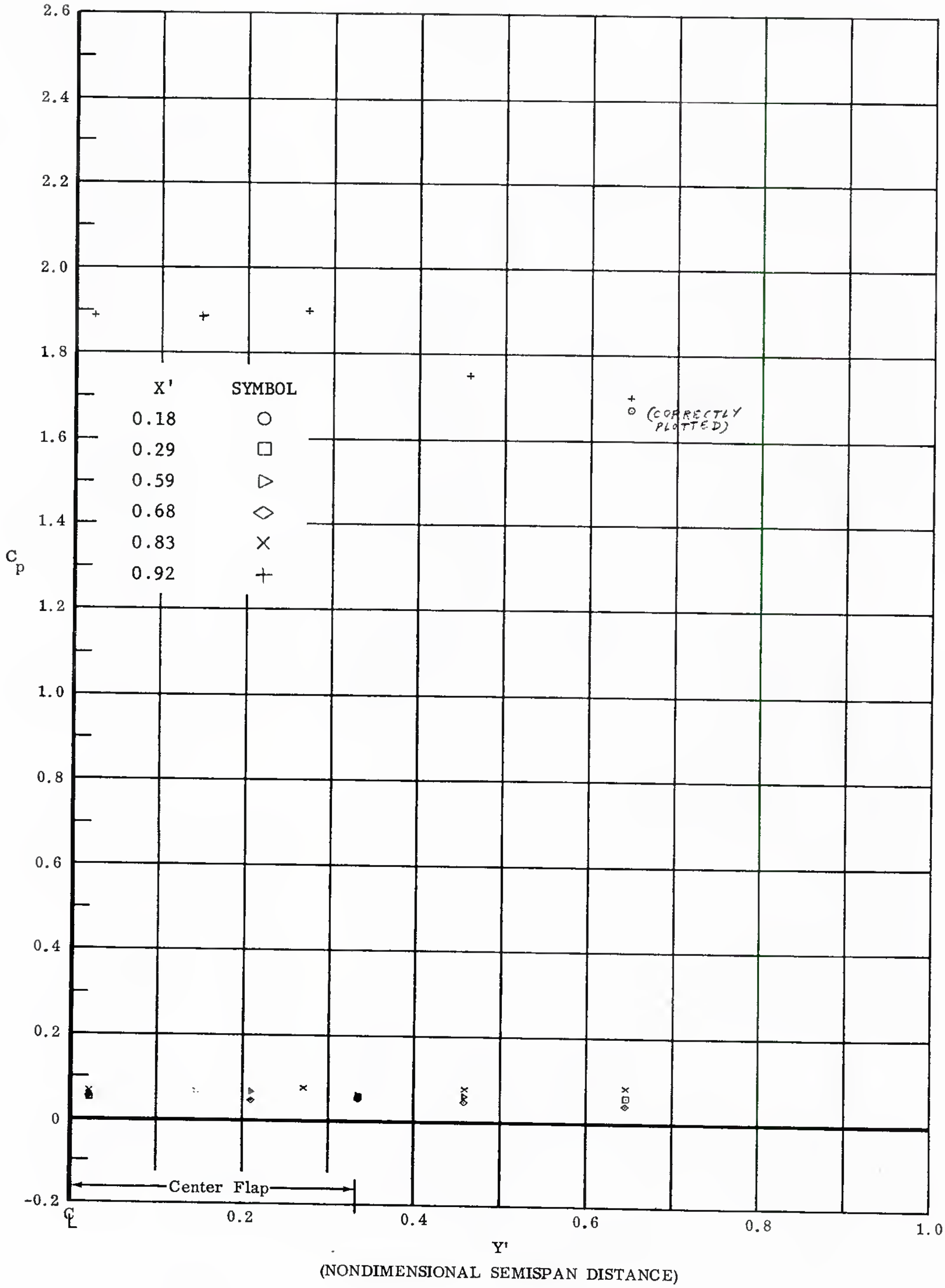


Fig. 36 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°*, $\alpha = 0$, $Re_\infty/ft = 1{,}100{,}000$

*See note in Table II, pages 6 and 7.

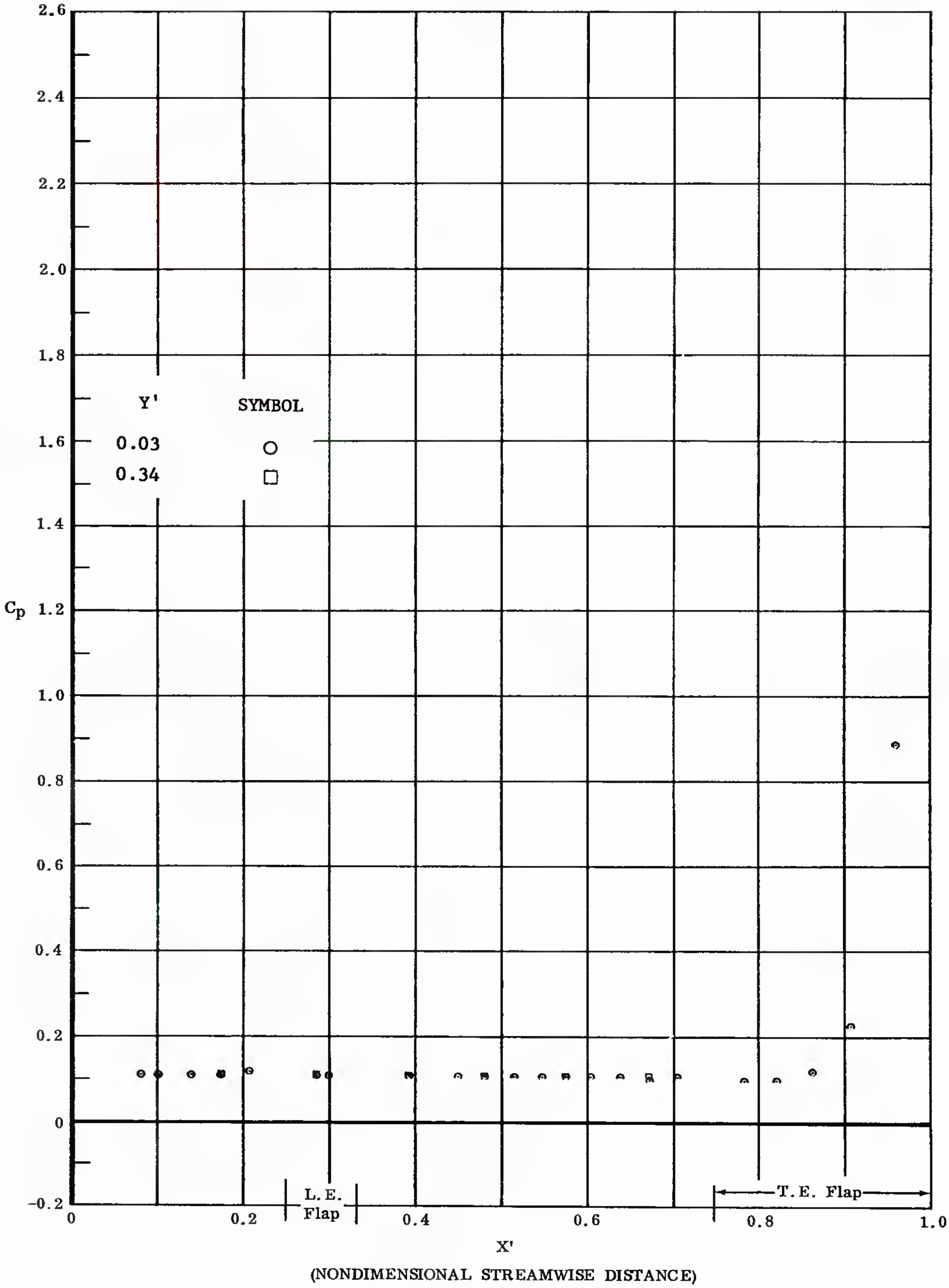


Fig. 37 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

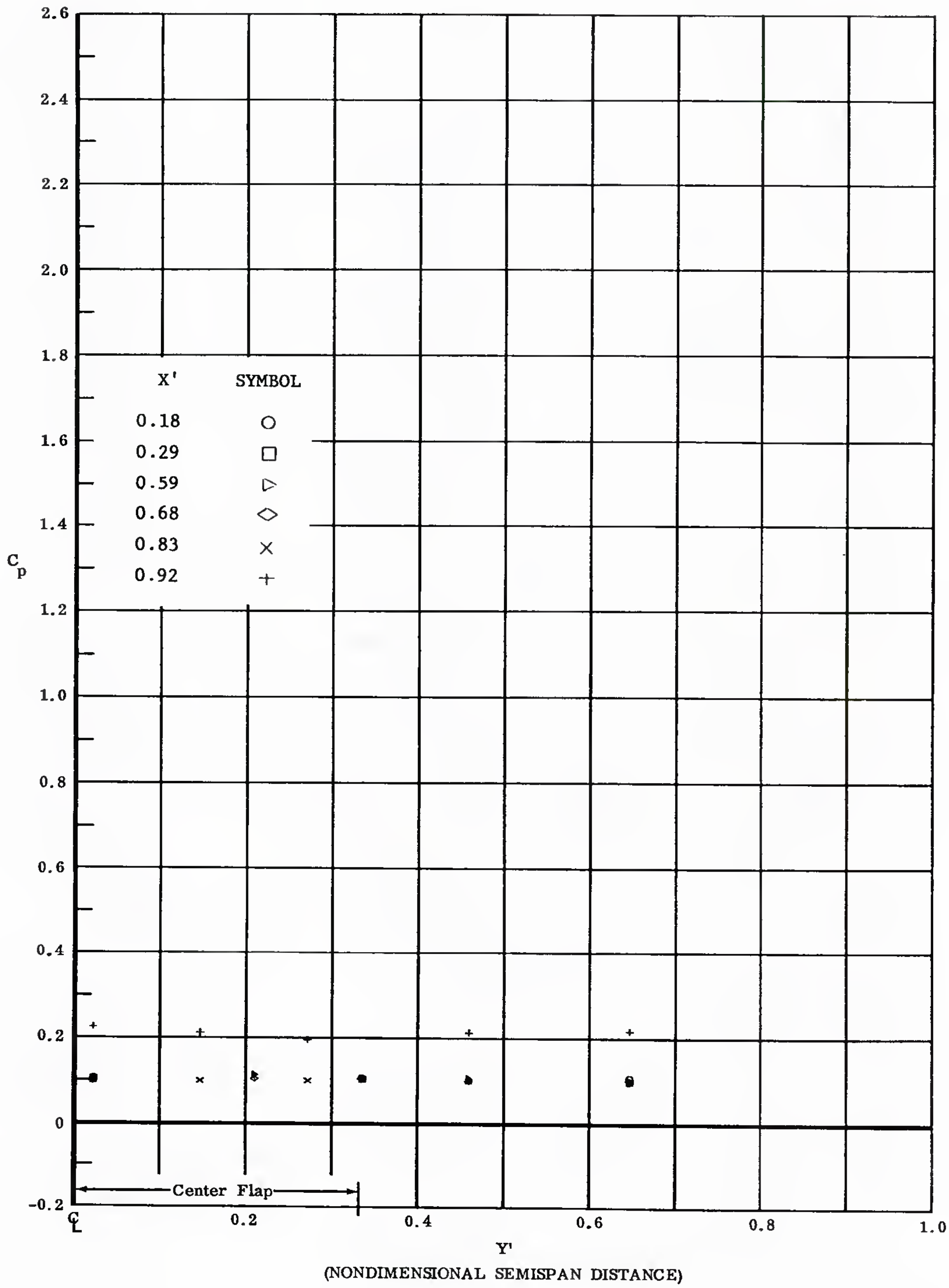


Fig. 37 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 1,100,000$

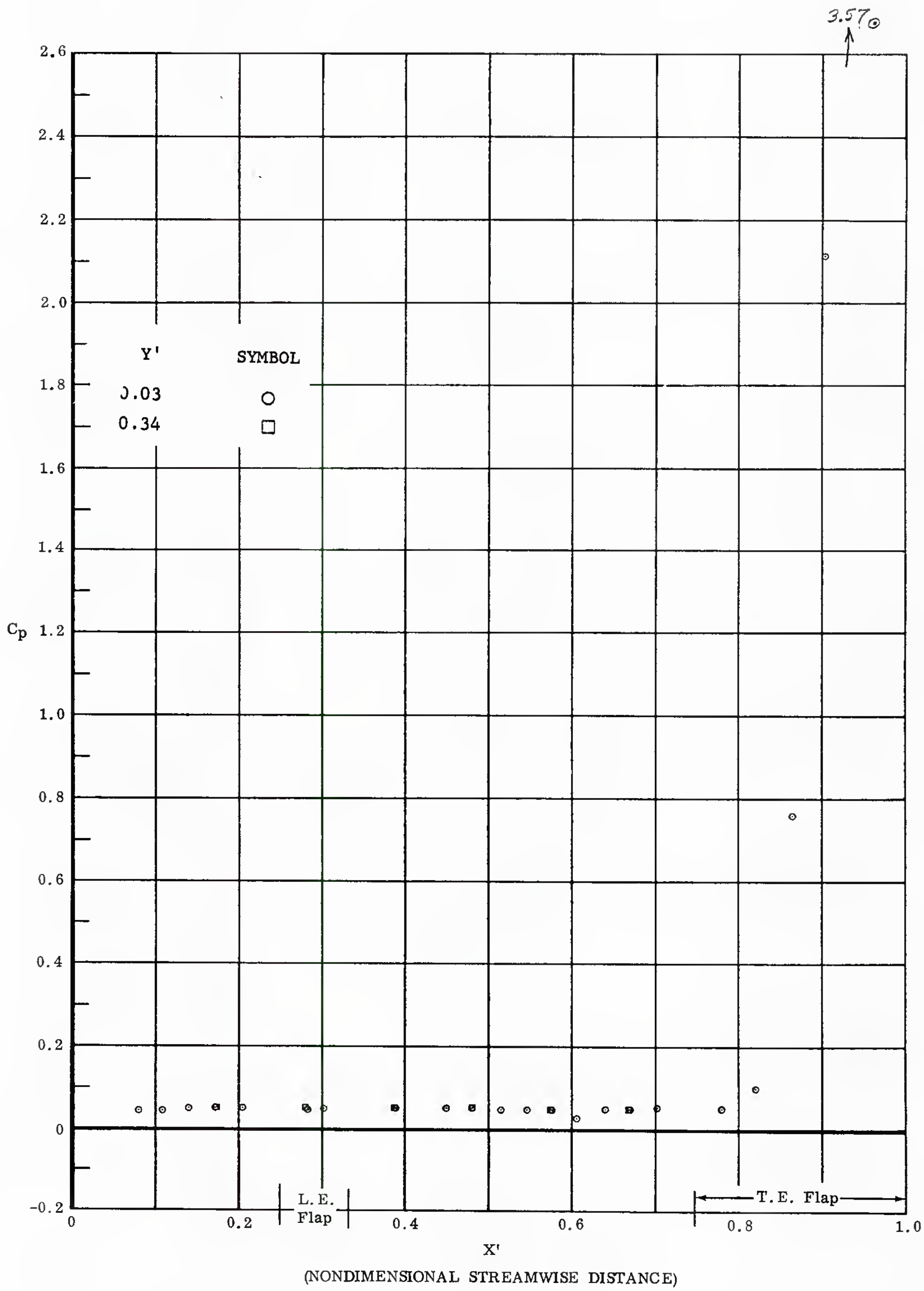


Fig. 38 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

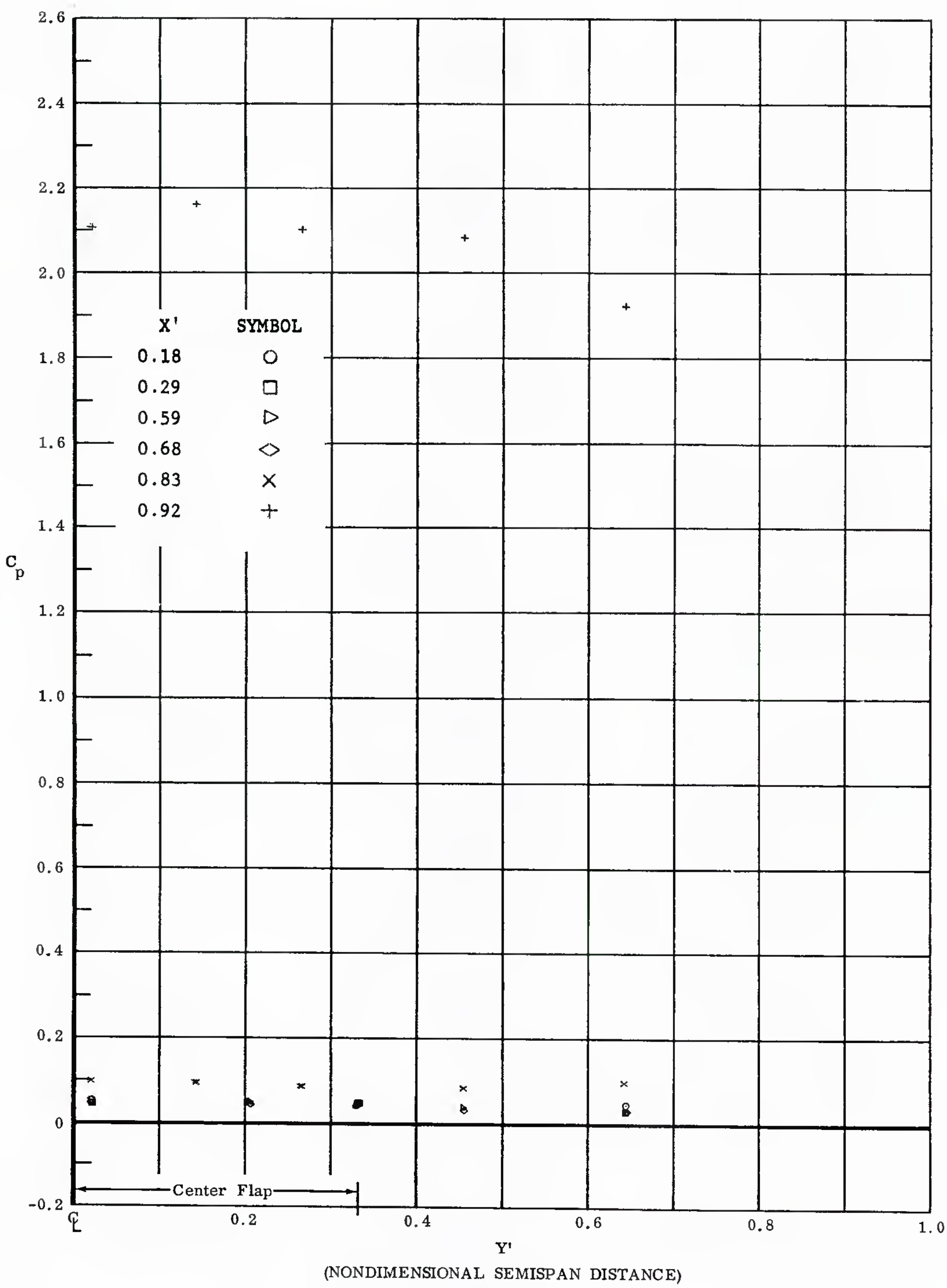


Fig. 38 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

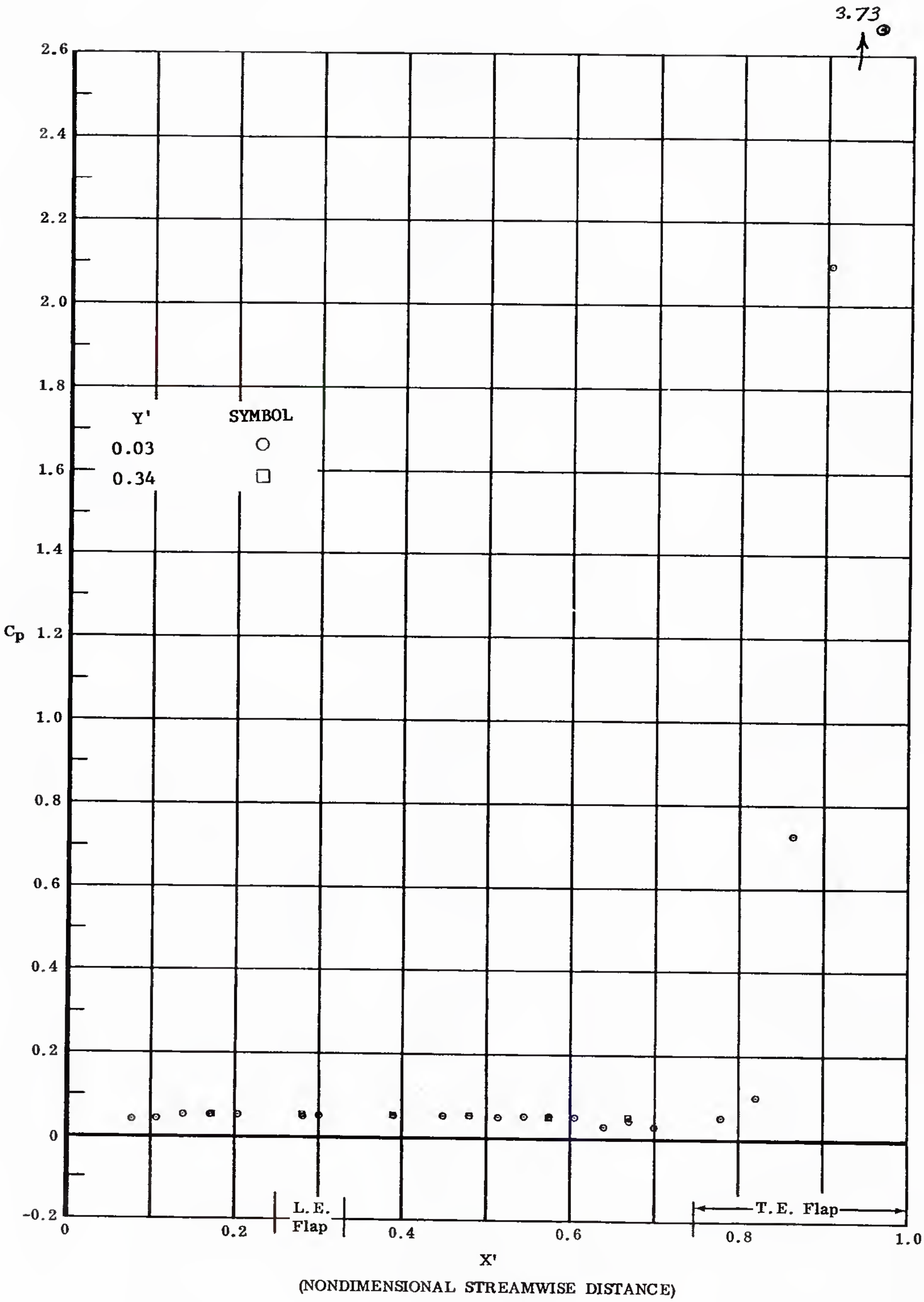


Fig. 39 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

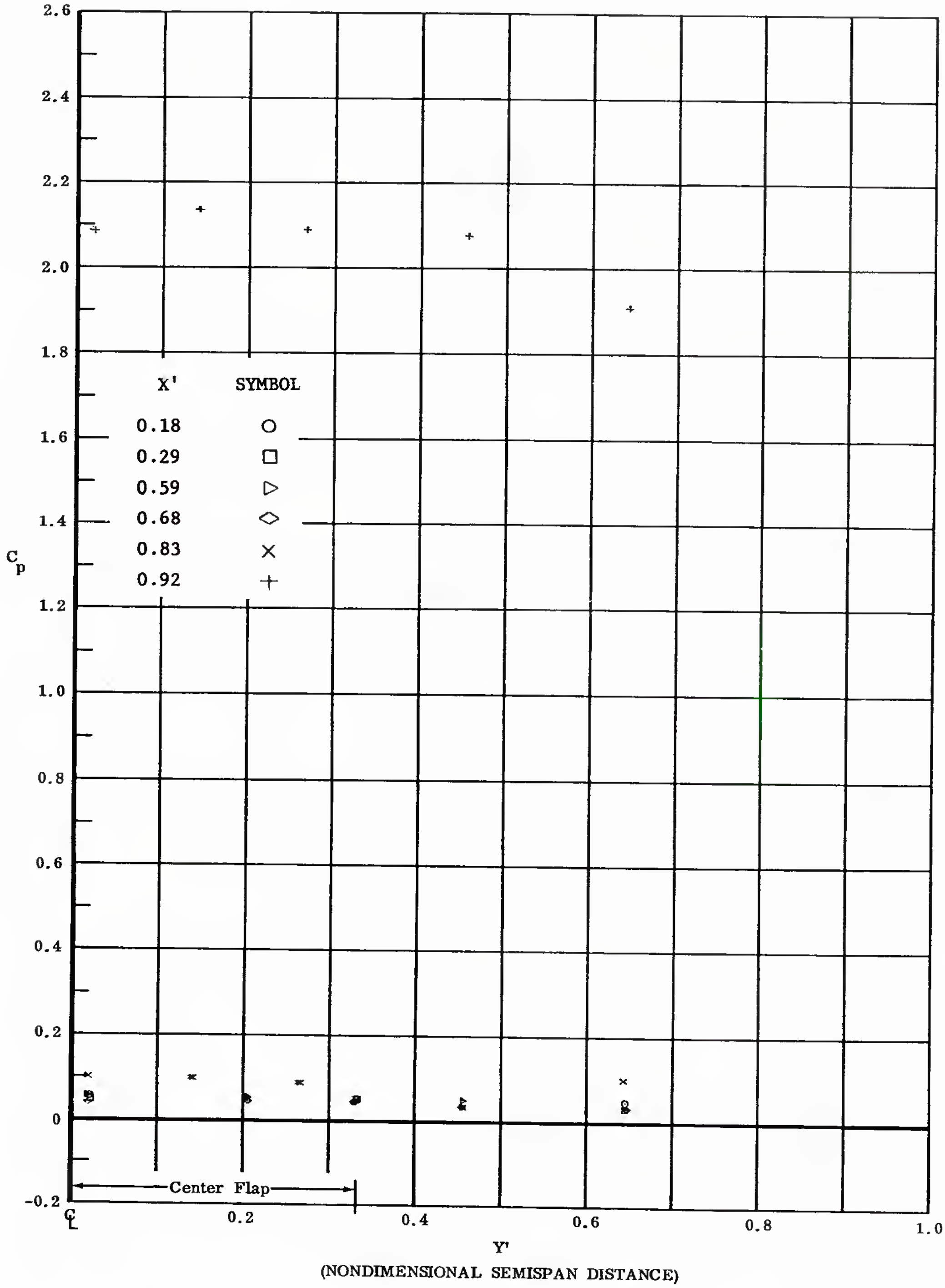


Fig. 39 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

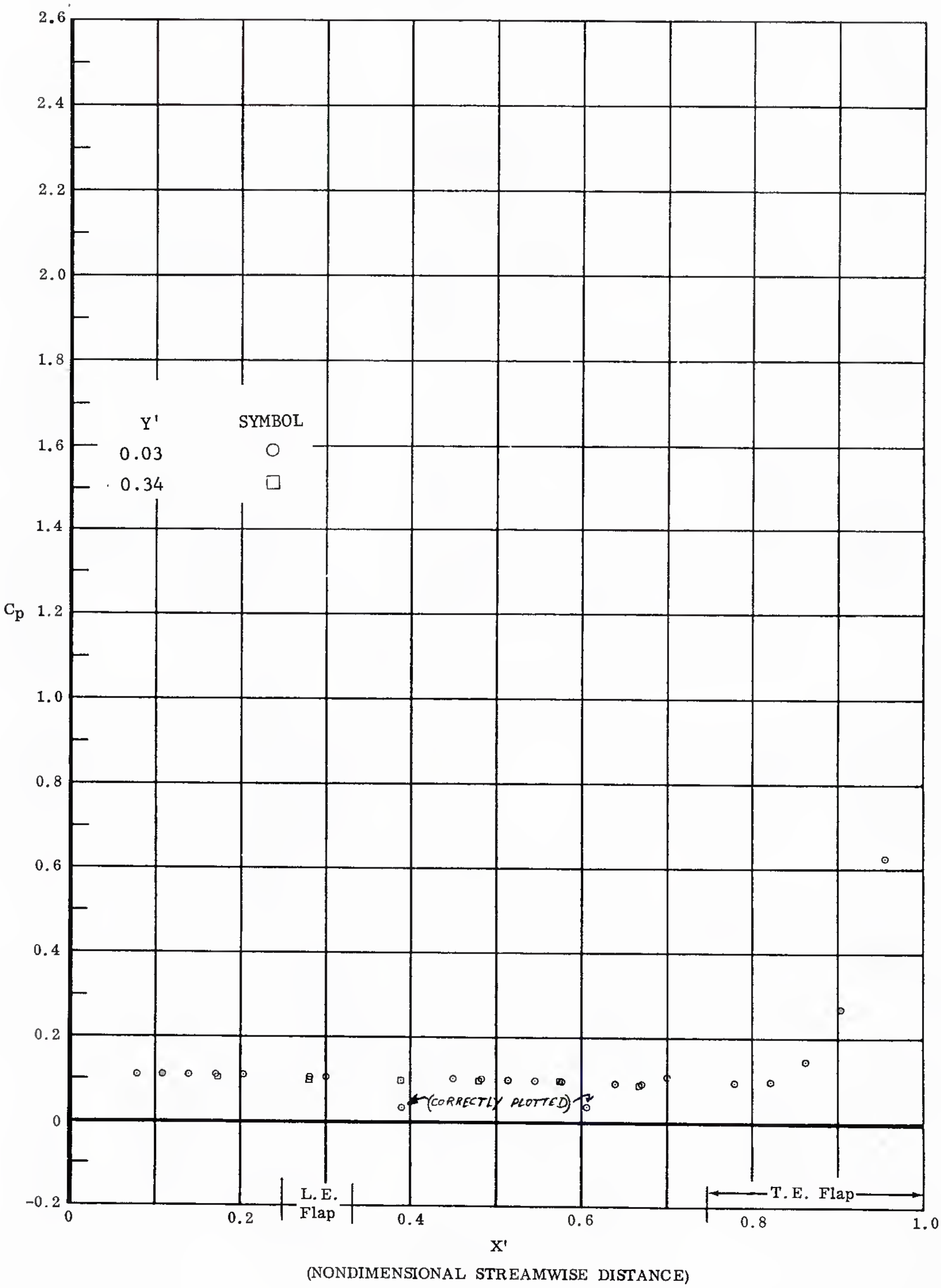


Fig. 40 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

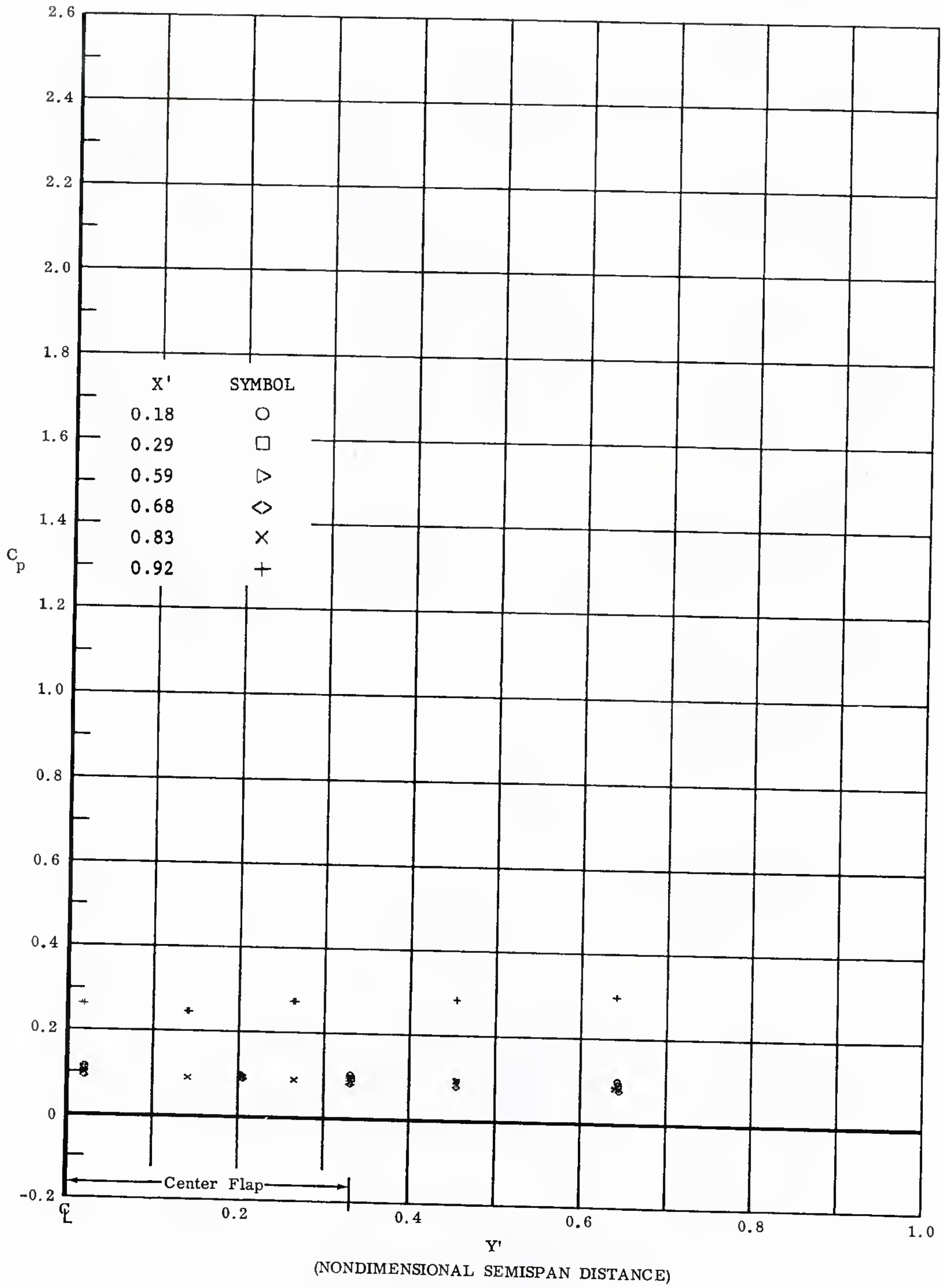


Fig. 40 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, $\alpha = 0$, $Re_\infty/ft = 3{,}300{,}000$

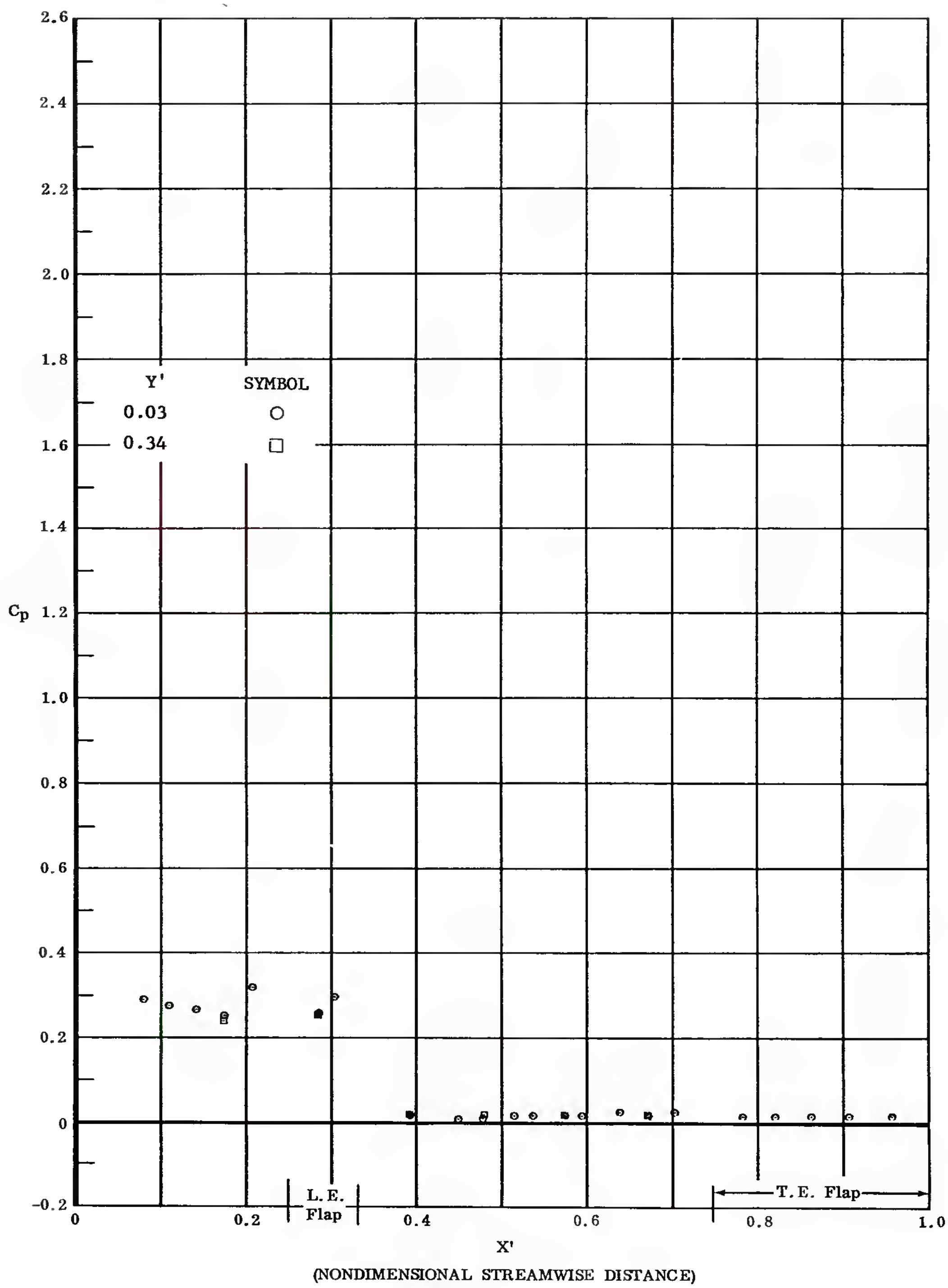


Fig. 41 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 90°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

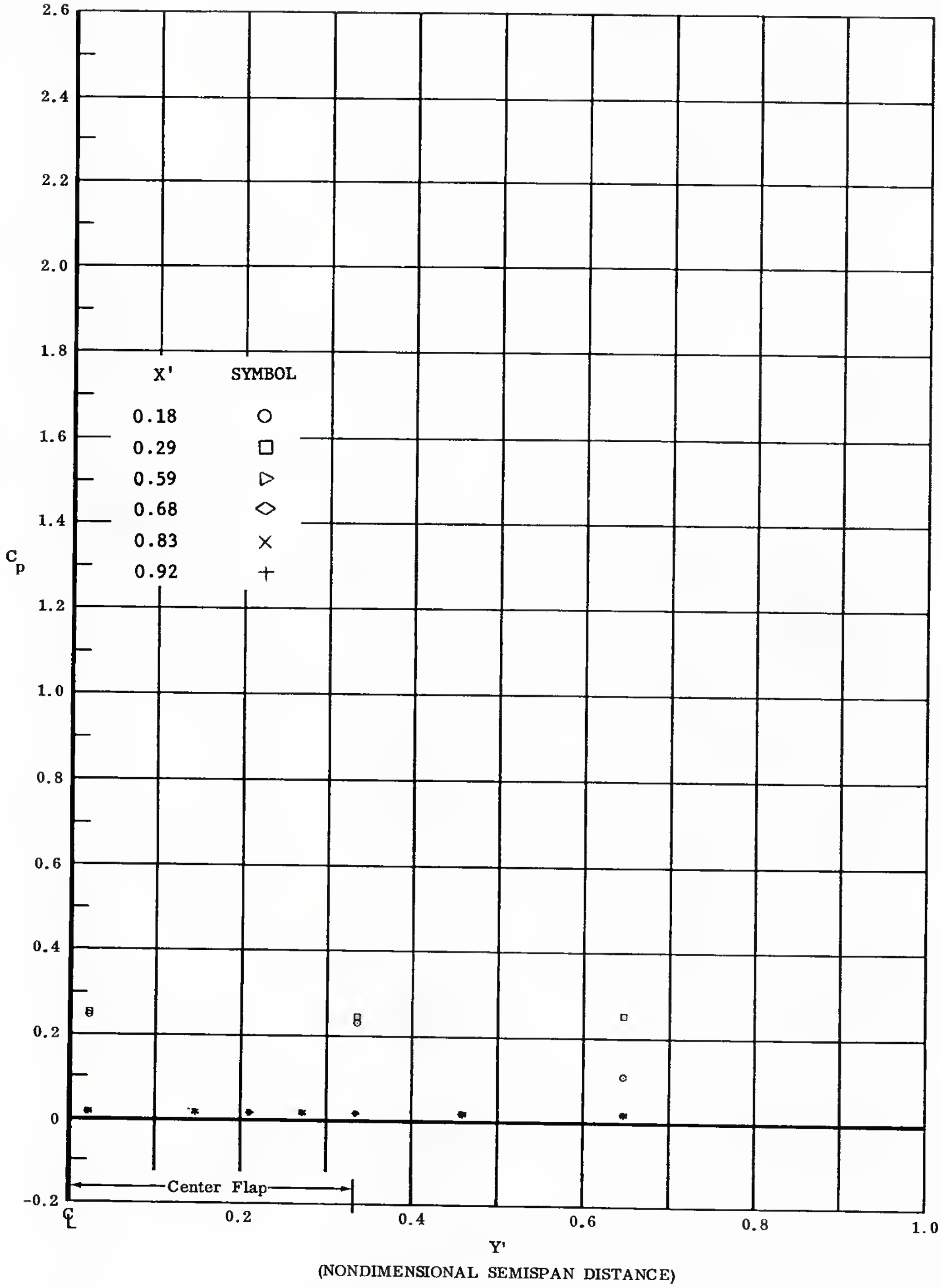


Fig. 41 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 90°, $\alpha = 0$, $Re_\infty/ft = 3,300,000$

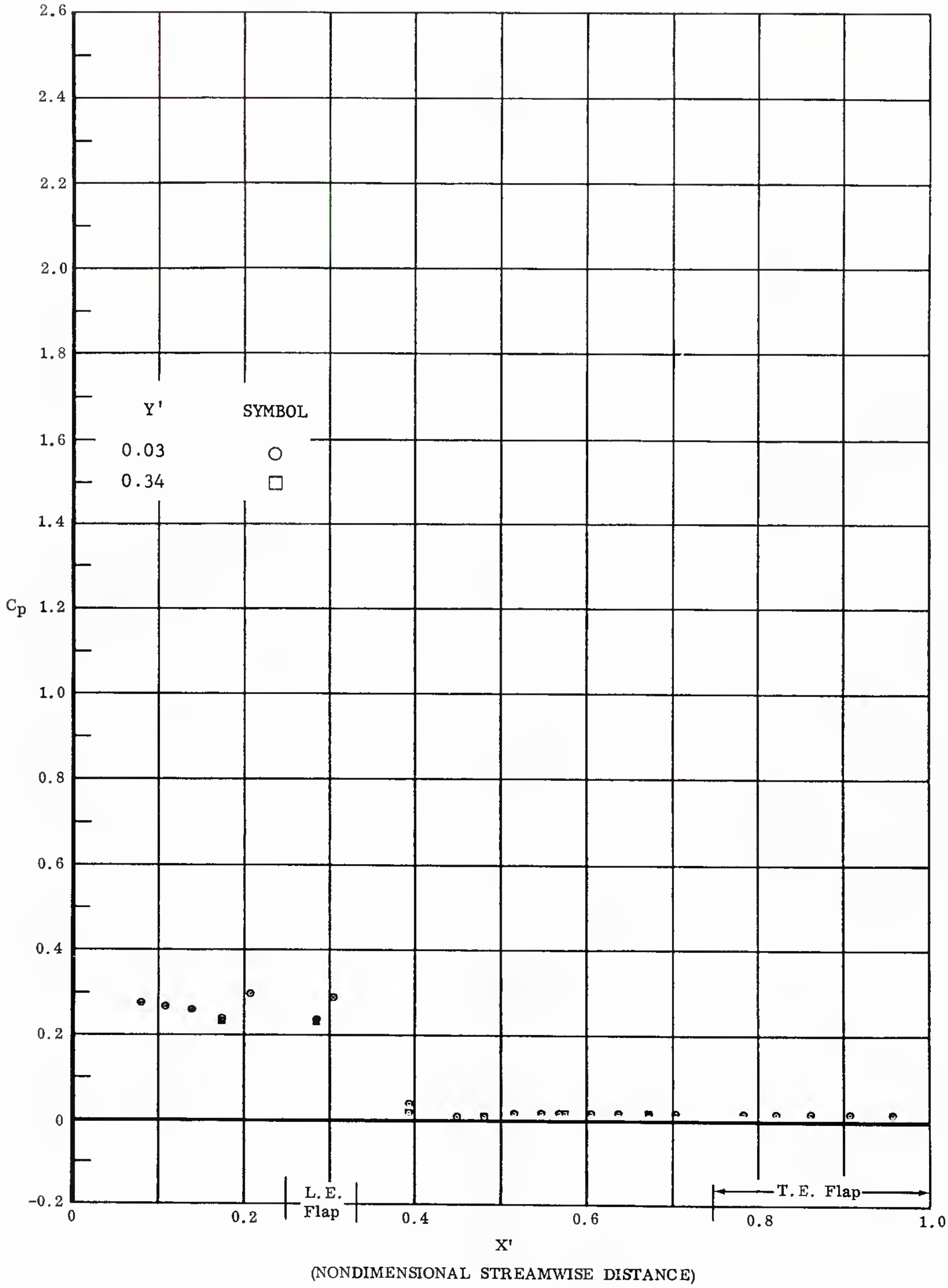


Fig. 42 Streamwise Pressure Distributions; End Plates On, Forward Flap Deflected 90°, $\alpha = 0$, $Re_{\infty}/ft = 3,300,000$

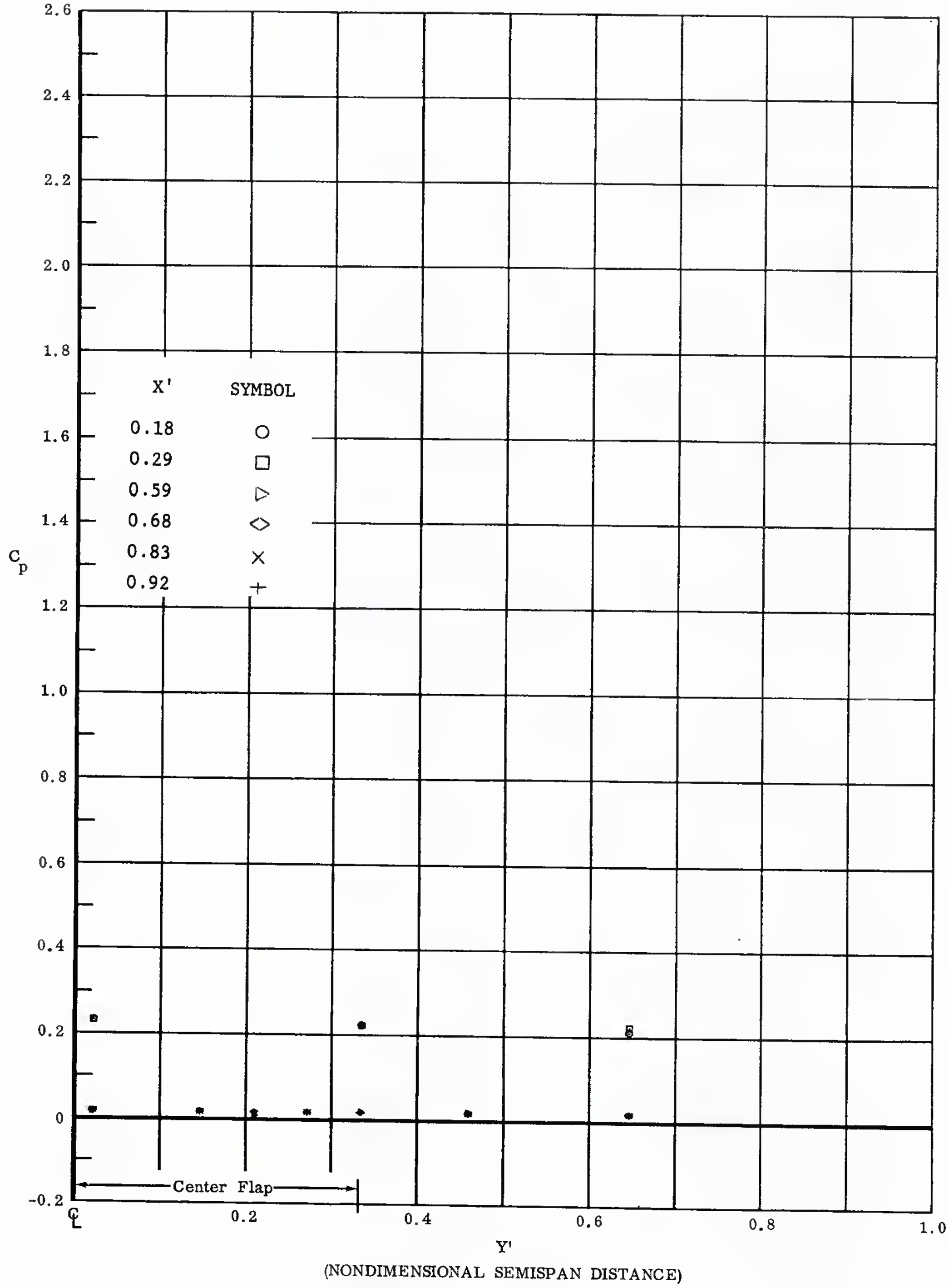


Fig. 42 Spanwise Pressure Distributions; End Plates On, Forward Flap Deflected 90°, $\alpha = 0$, $Re_{\infty}/ft = 3{,}300{,}000$

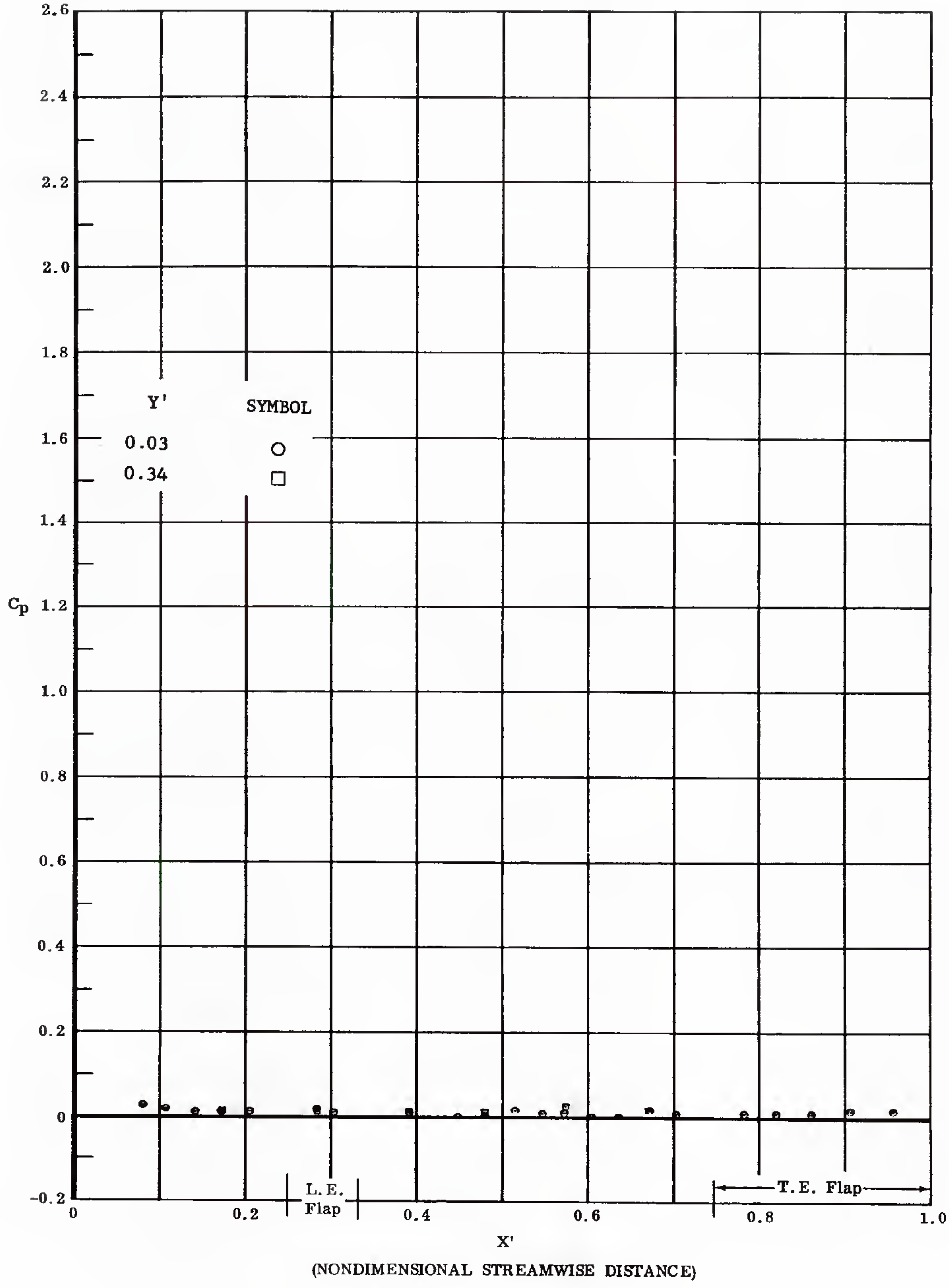


Fig. 43 Streamwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = +5^{\circ}$, Re_{∞}/ft = 1,100,000

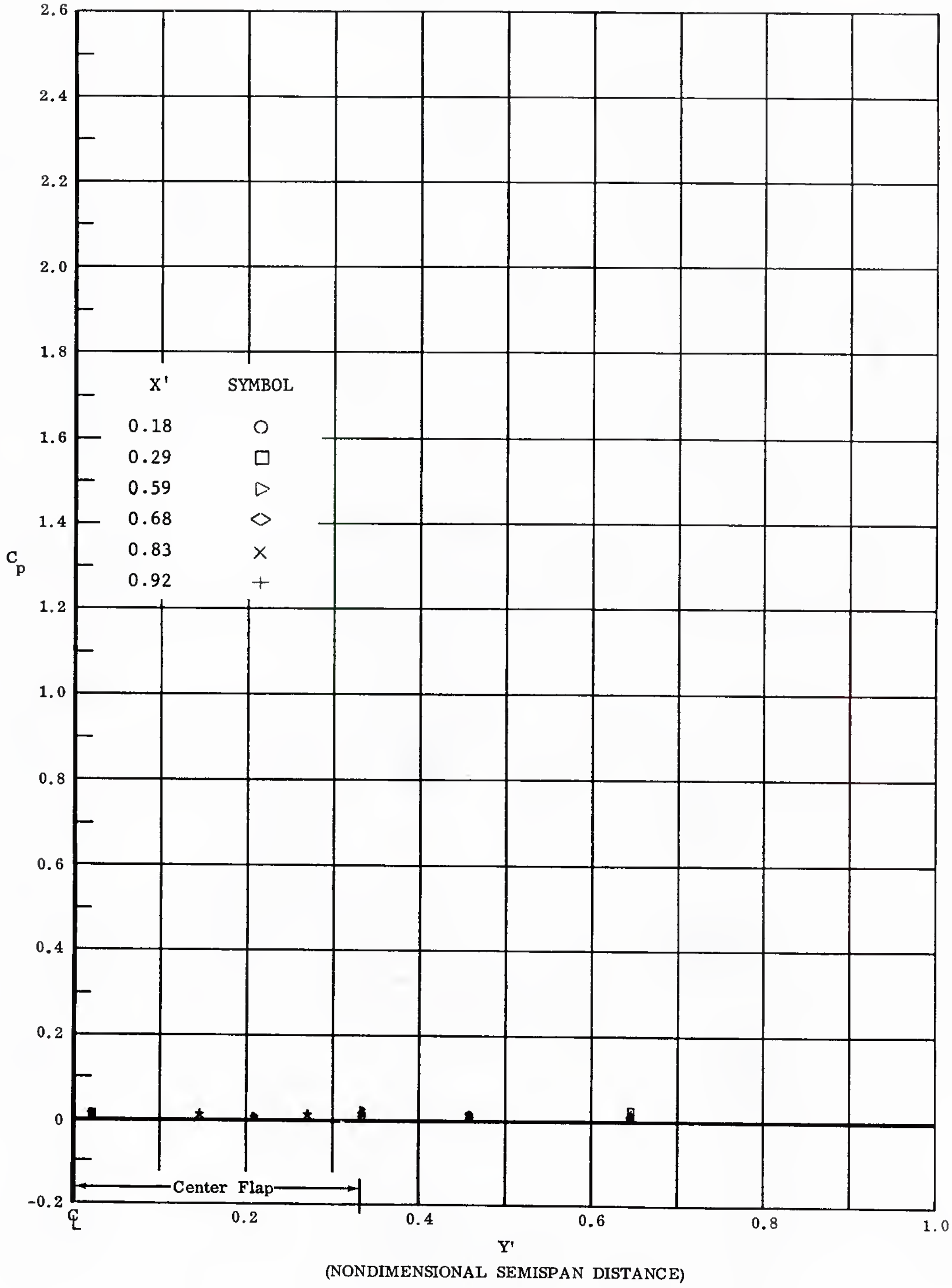


Fig. 43 Spanwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = +5°$, $Re_\infty/ft = 1{,}100{,}000$

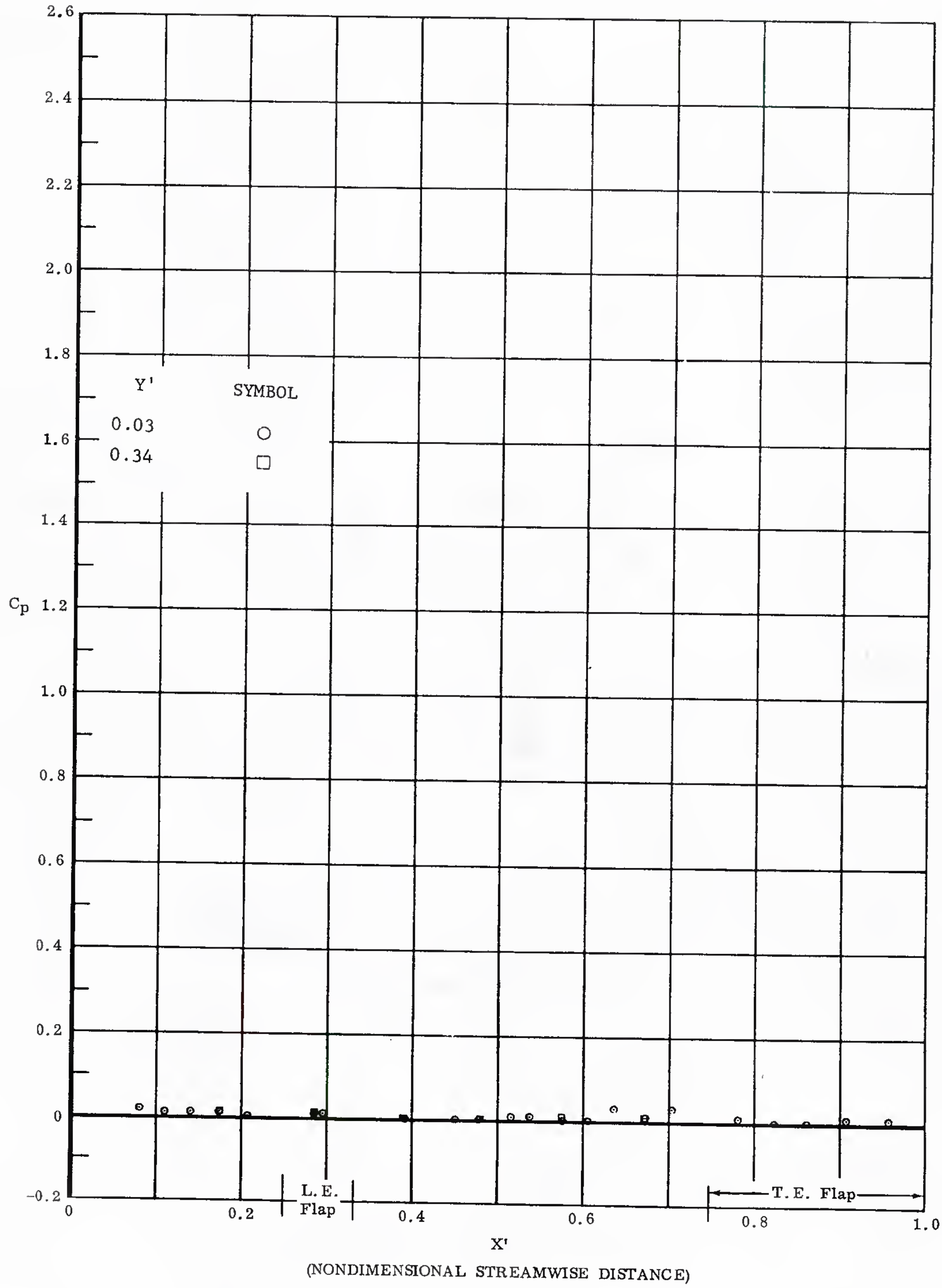


Fig. 44 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = +5^{\circ}$, $Re_{\infty}/ft = 2{,}200{,}000$

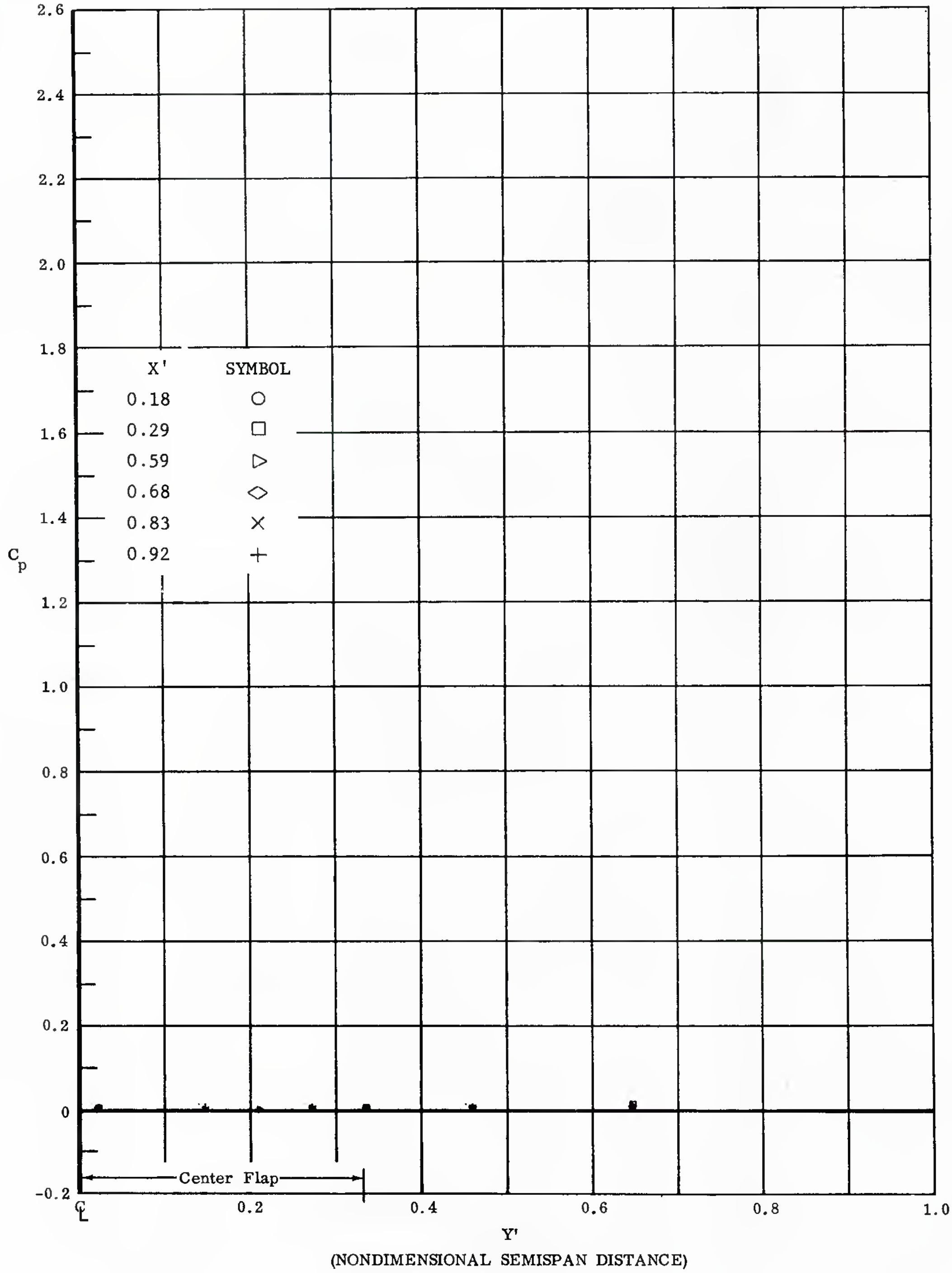


Fig. 44 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = +5°$, Re_∞/ft = 2,200,000

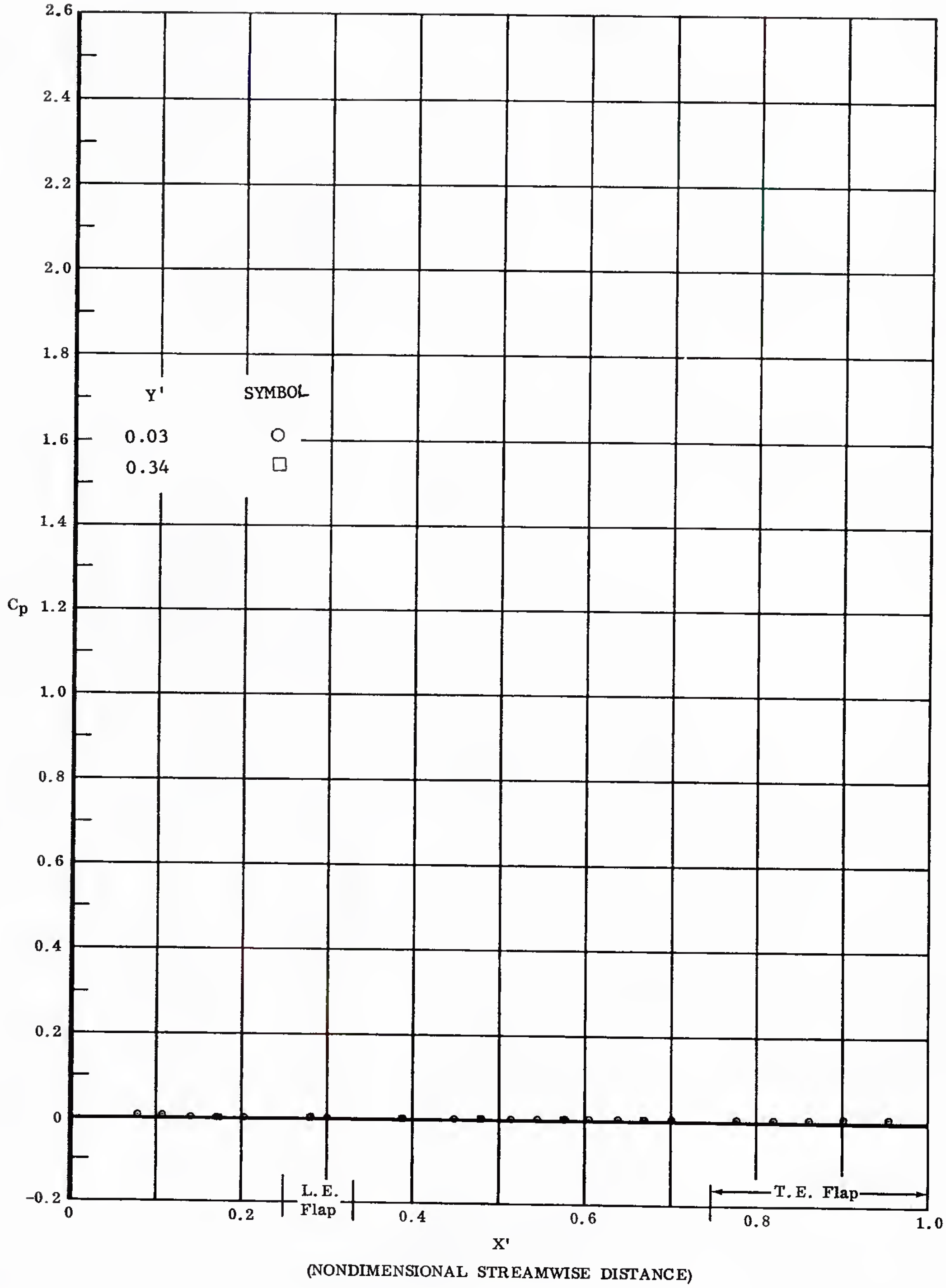


Fig. 45 Streamwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = +5°$, Re_∞/ft = 3,300,000

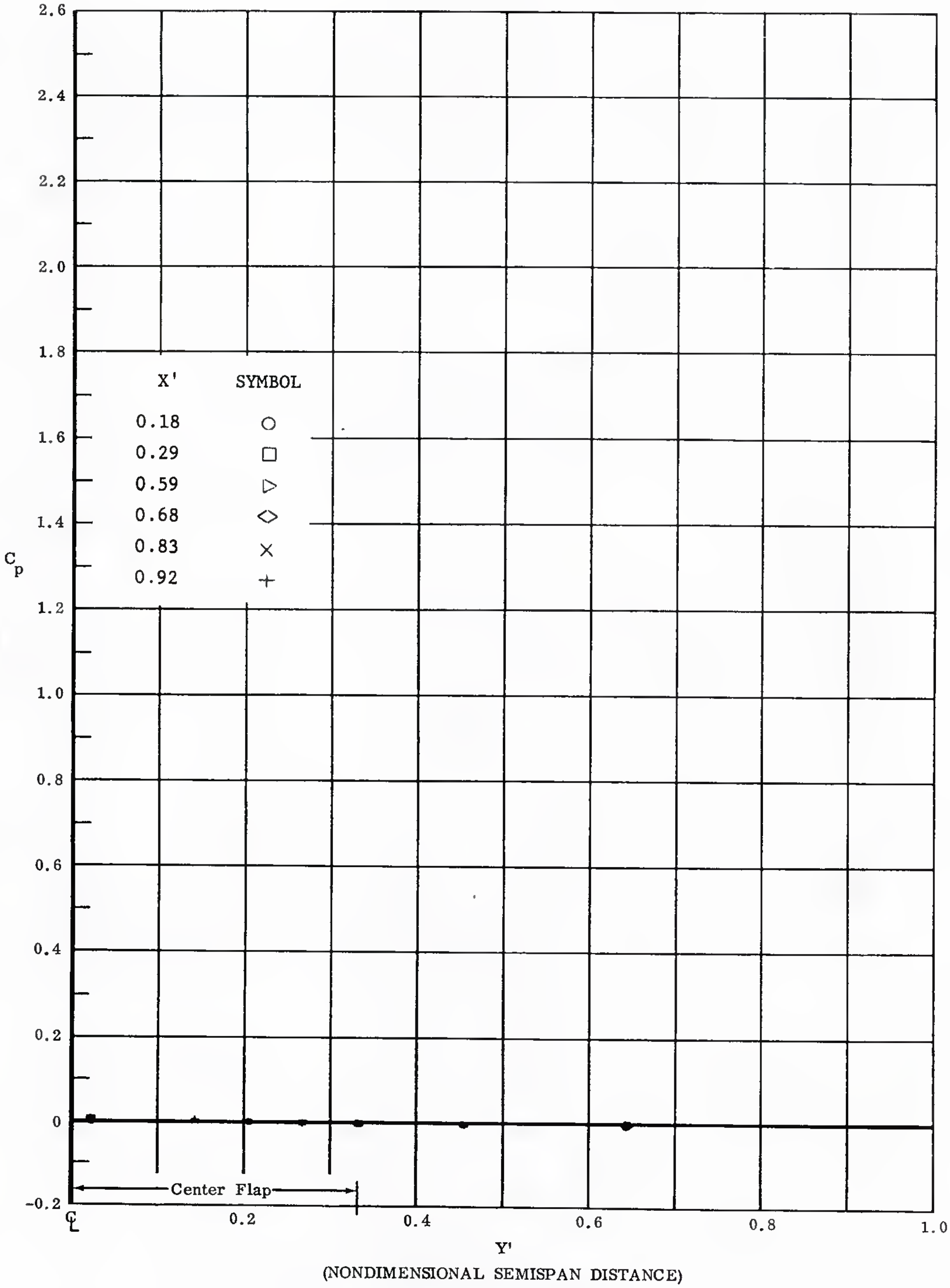


Fig. 45 Spanwise Pressure Distributions; End Plates Off, No Flap Deflections, $\alpha = +5^{\circ}$, $Re_{\infty}/ft = 3,300,000$

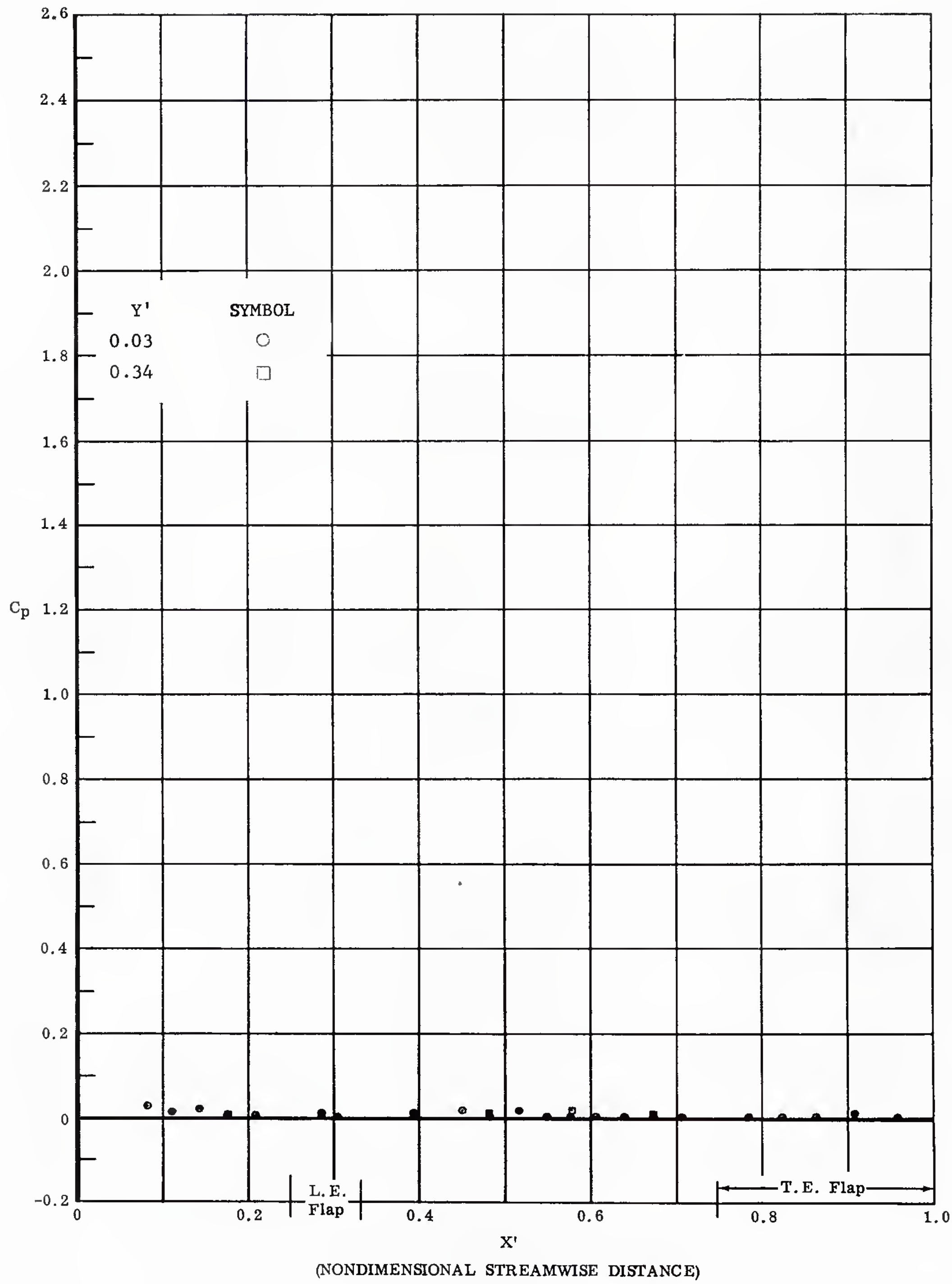


Fig. 46 Streamwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

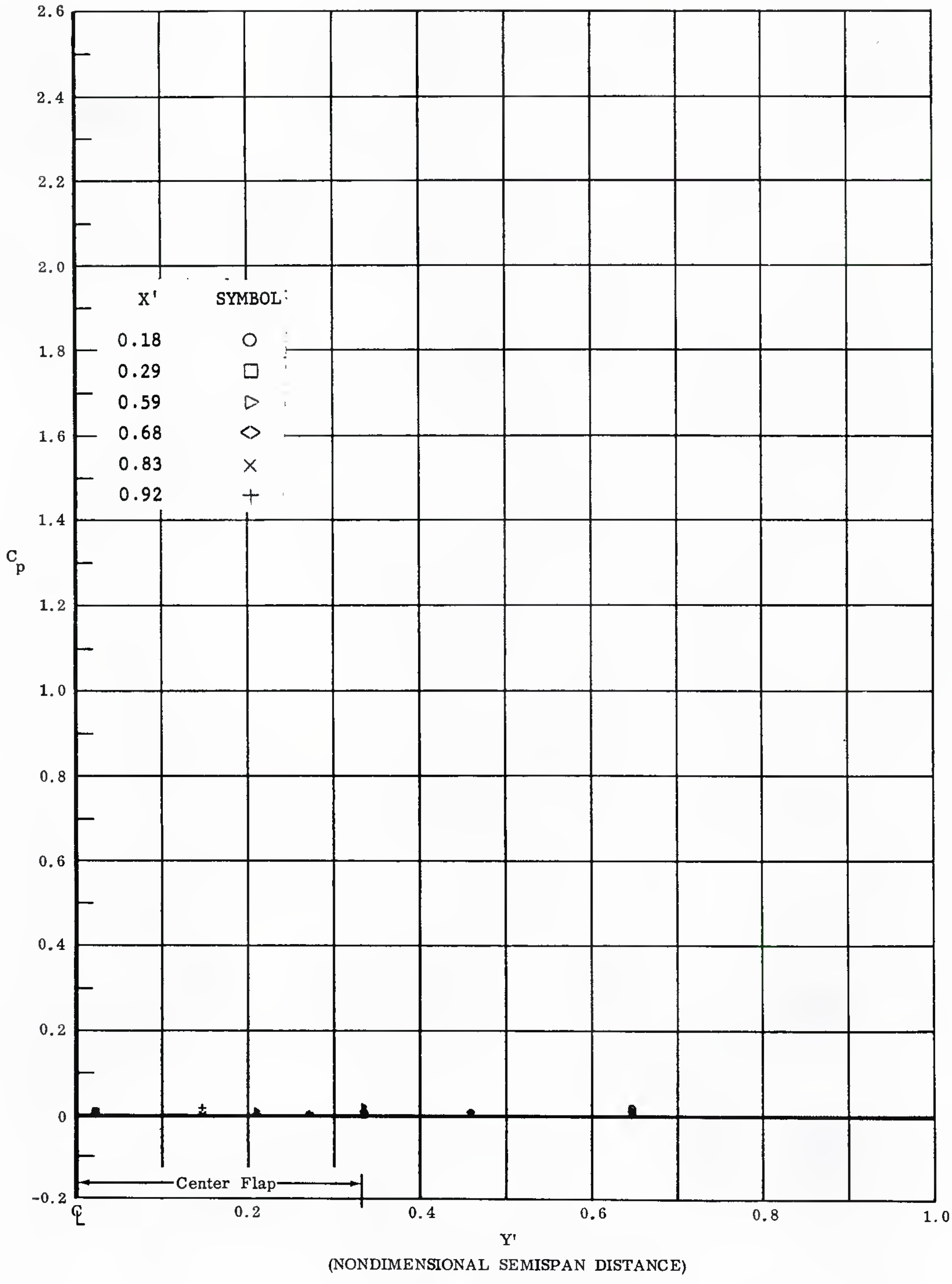


Fig. 46 Spanwise Pressure Distributions; End Plates On, No Flap Deflections, $\alpha = +5^{\circ}$, $Re_{\infty}/ft = 3{,}300{,}000$

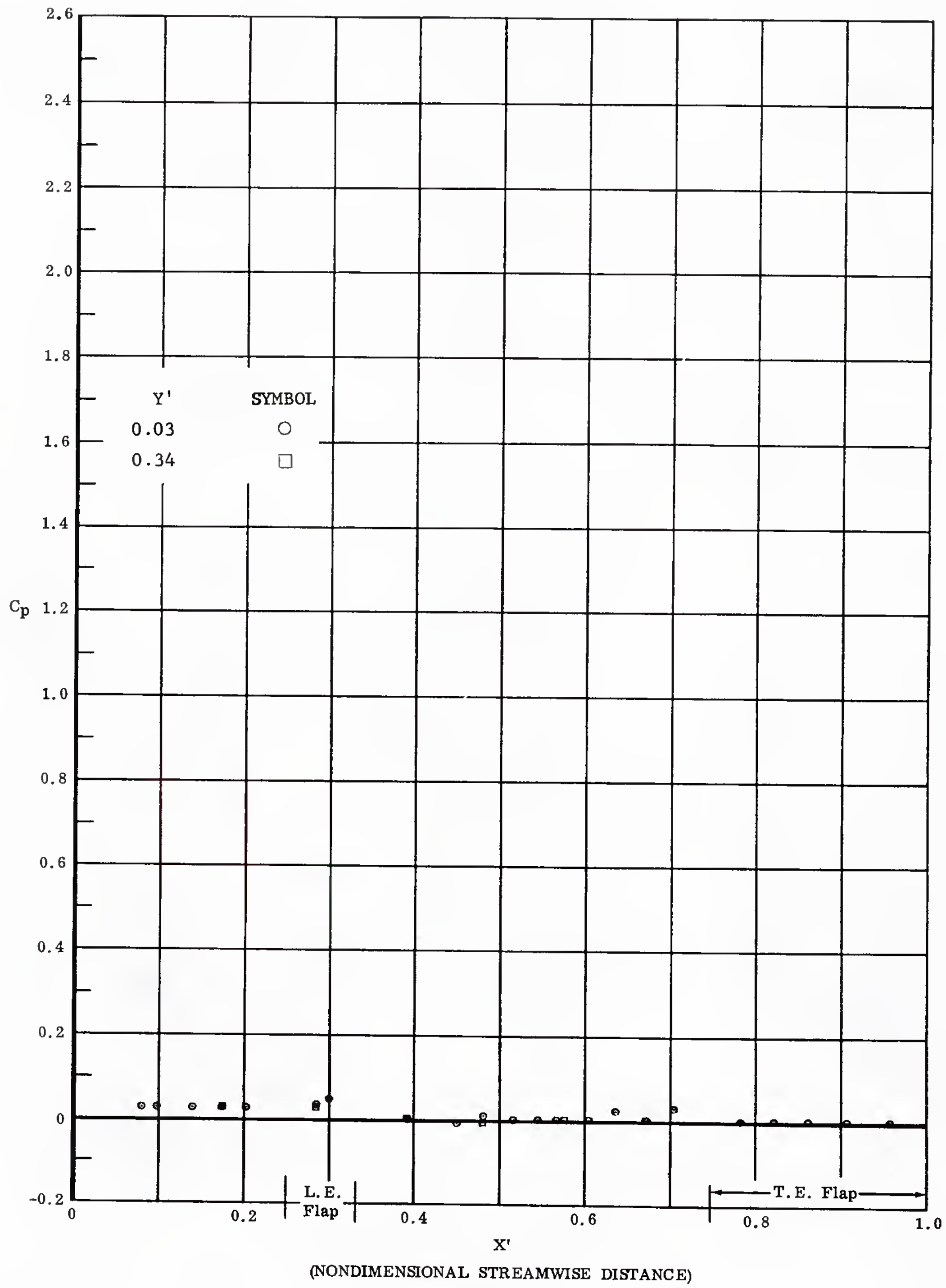


Fig. 47 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, $\alpha = +5°$, Re_∞/ft = 3,300,000

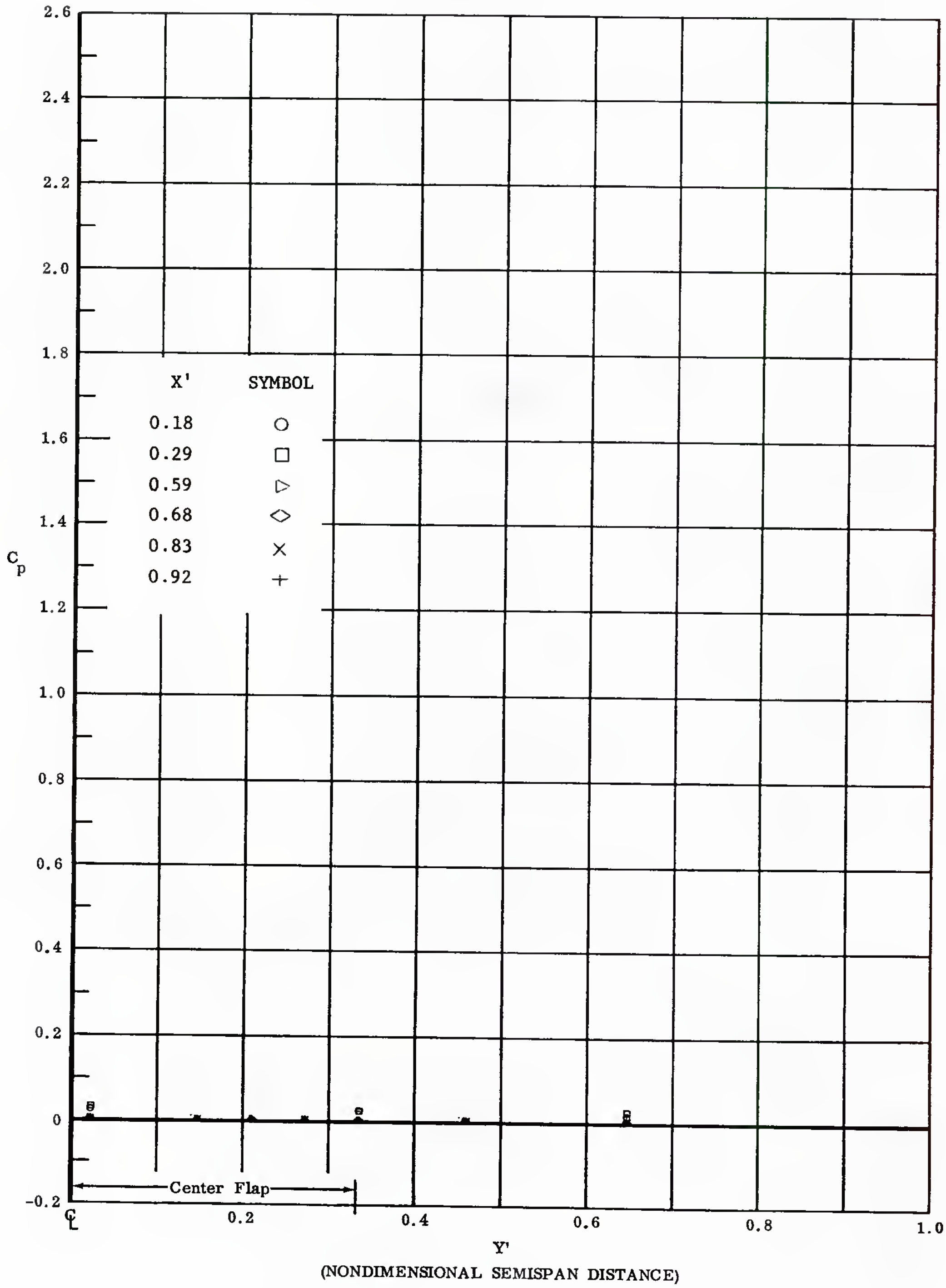


Fig. 47 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

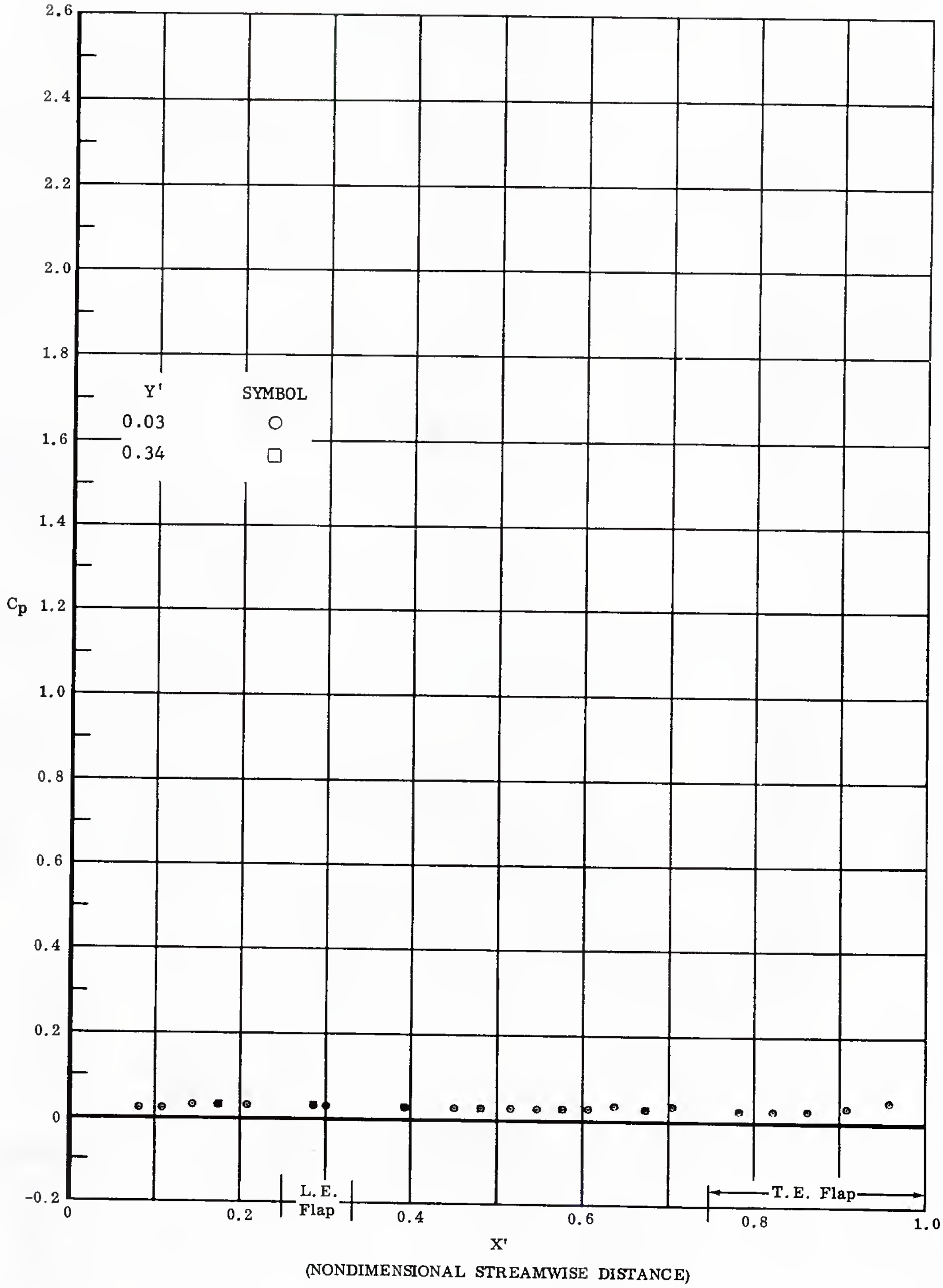


Fig. 48 Streamwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, Re_∞/ft = 2,200,000

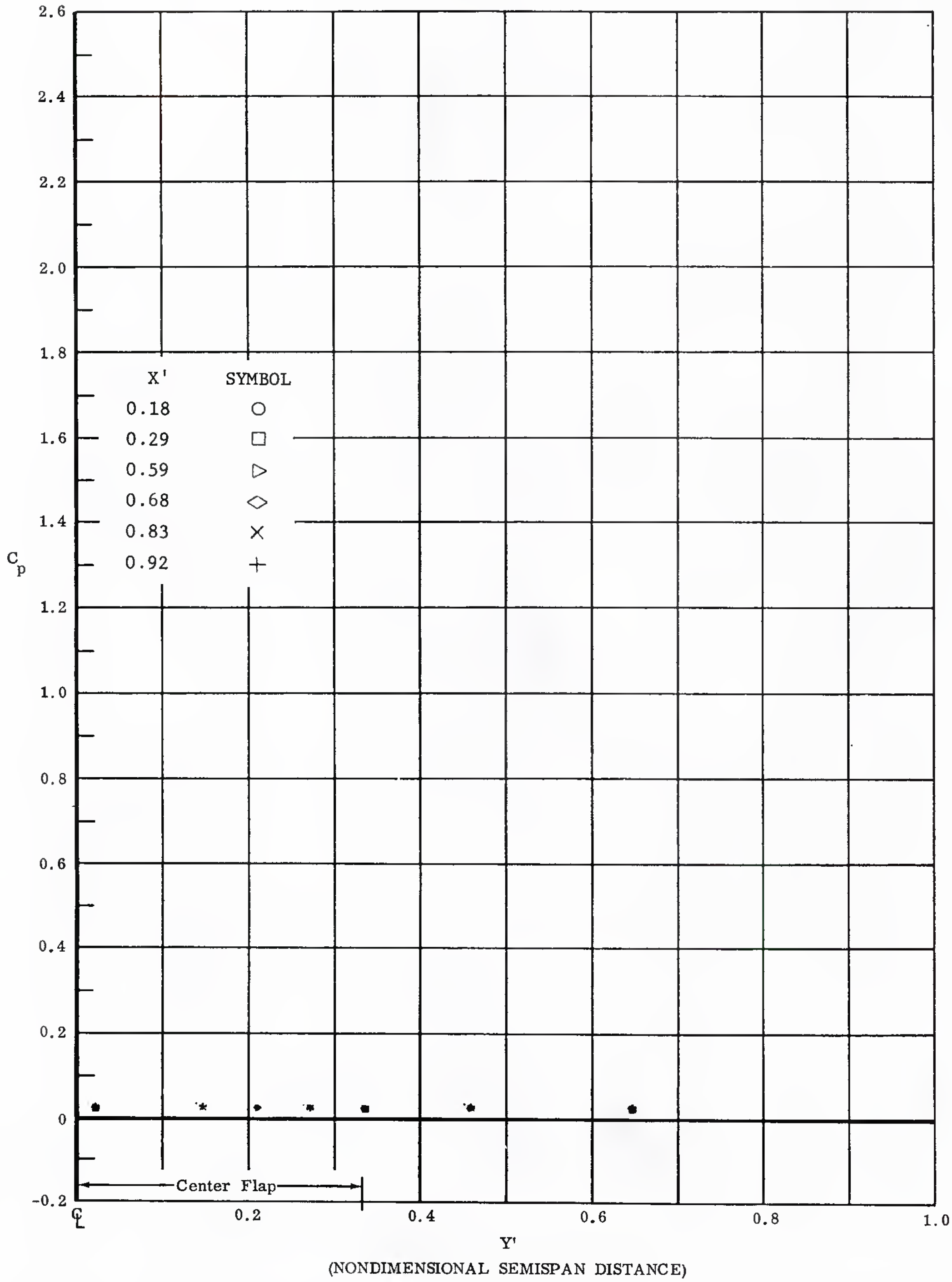


Fig. 48 Spanwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, α= +5°, Re_∞/ft = 2,200,000

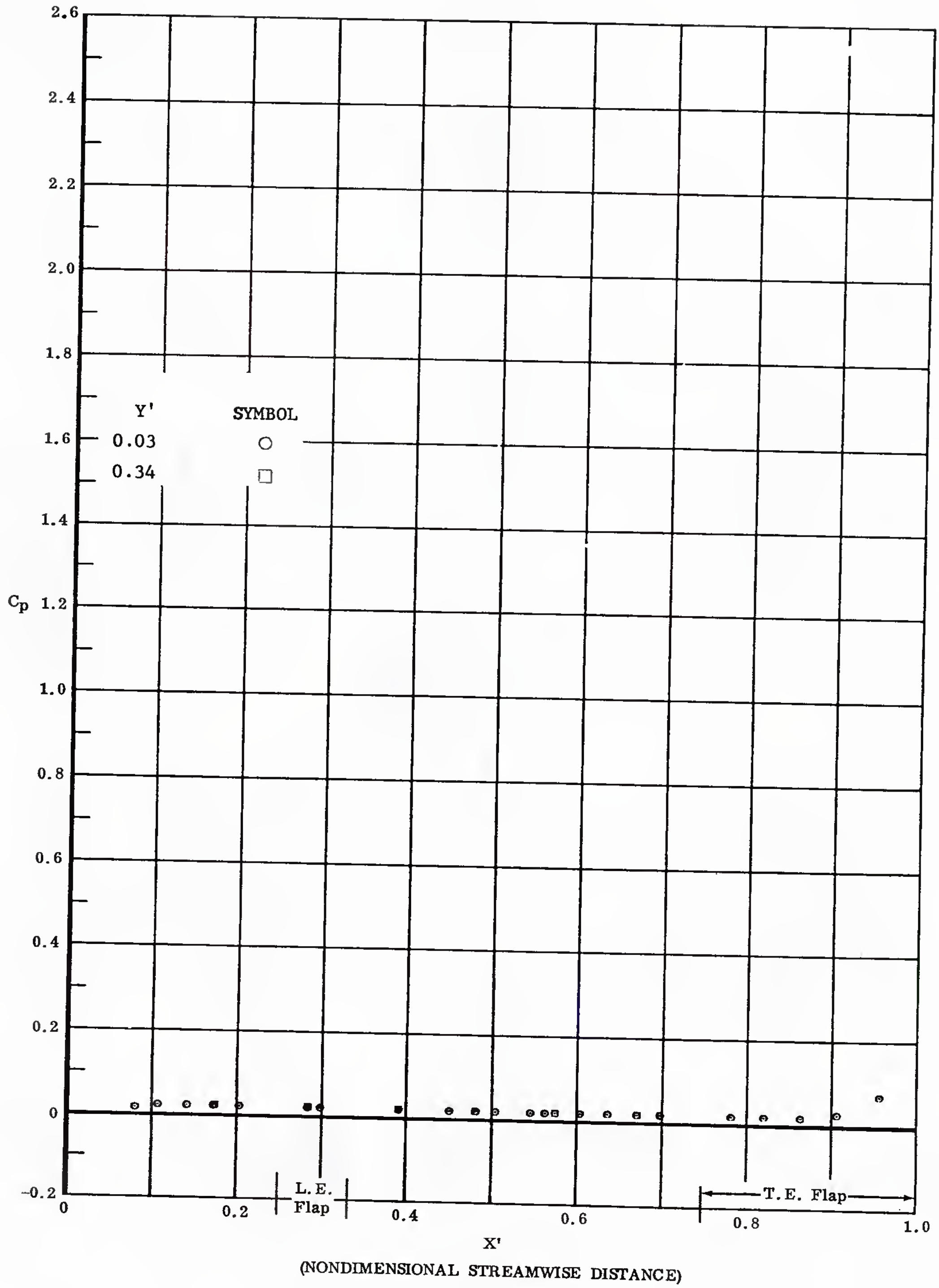


Fig. 49 Streamwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

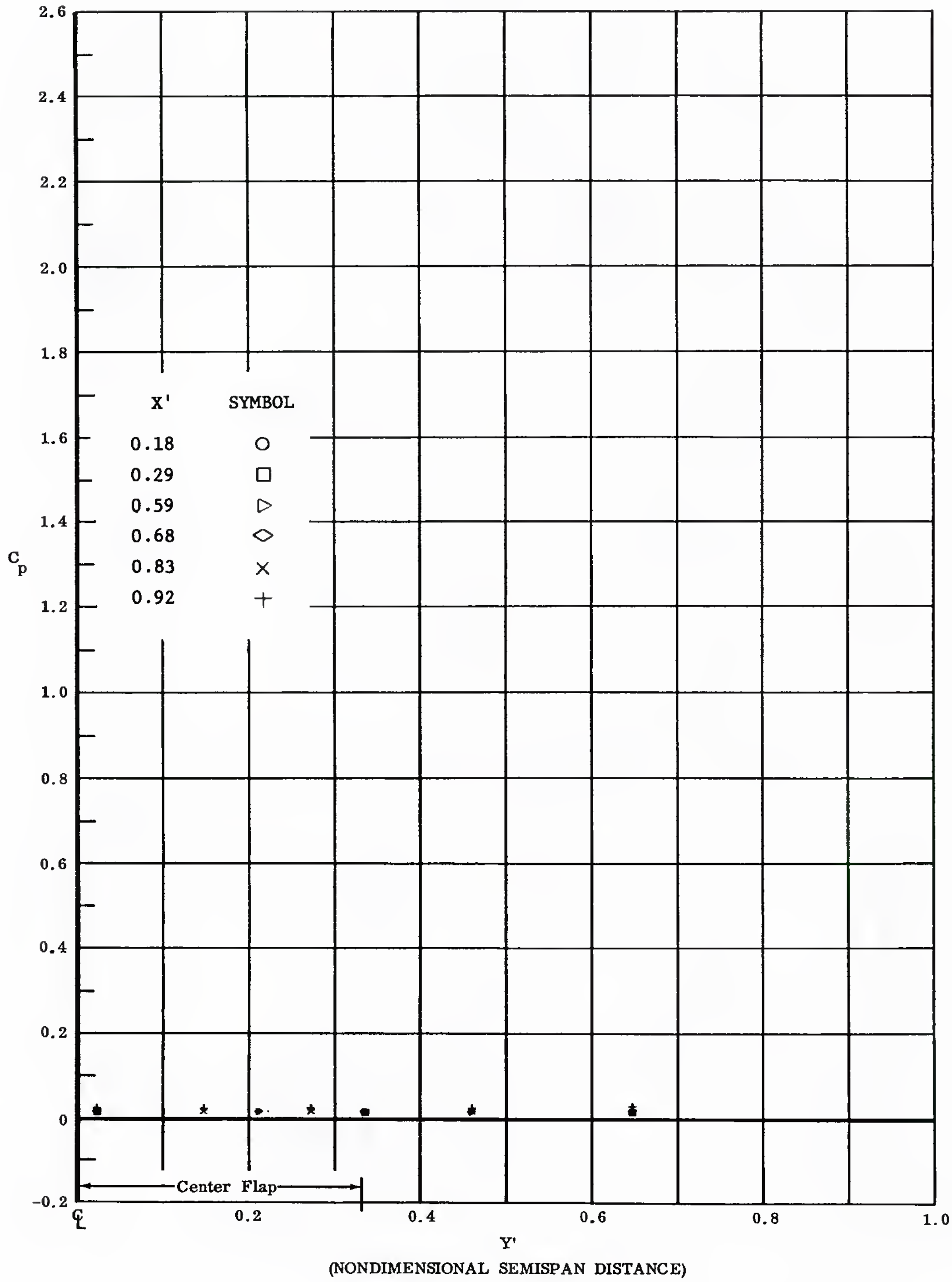


Fig. 49 Spanwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3{,}300{,}000$

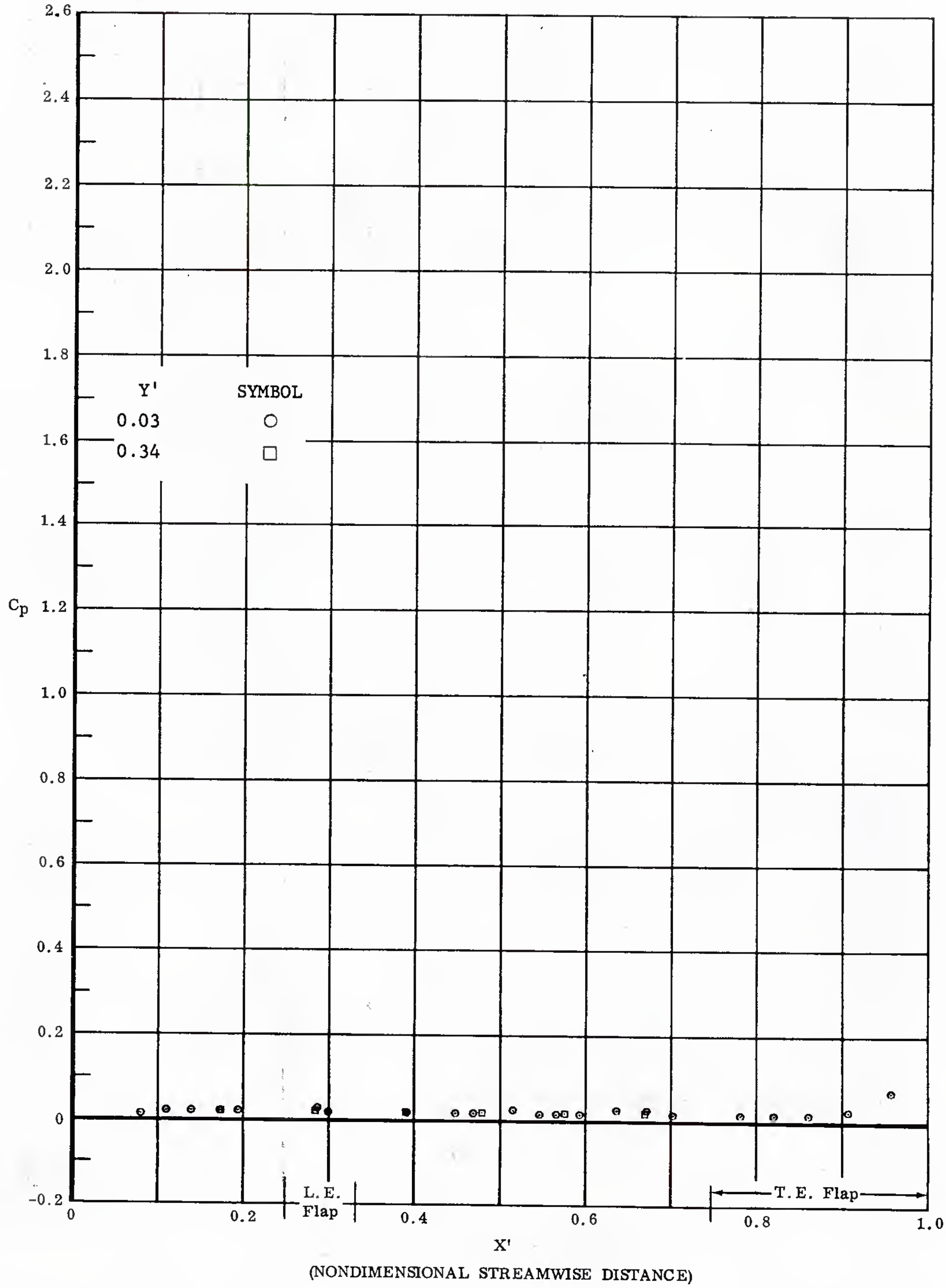


Fig. 50 Streamwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, α= +5°, Re_∞/ft = 3,300,000

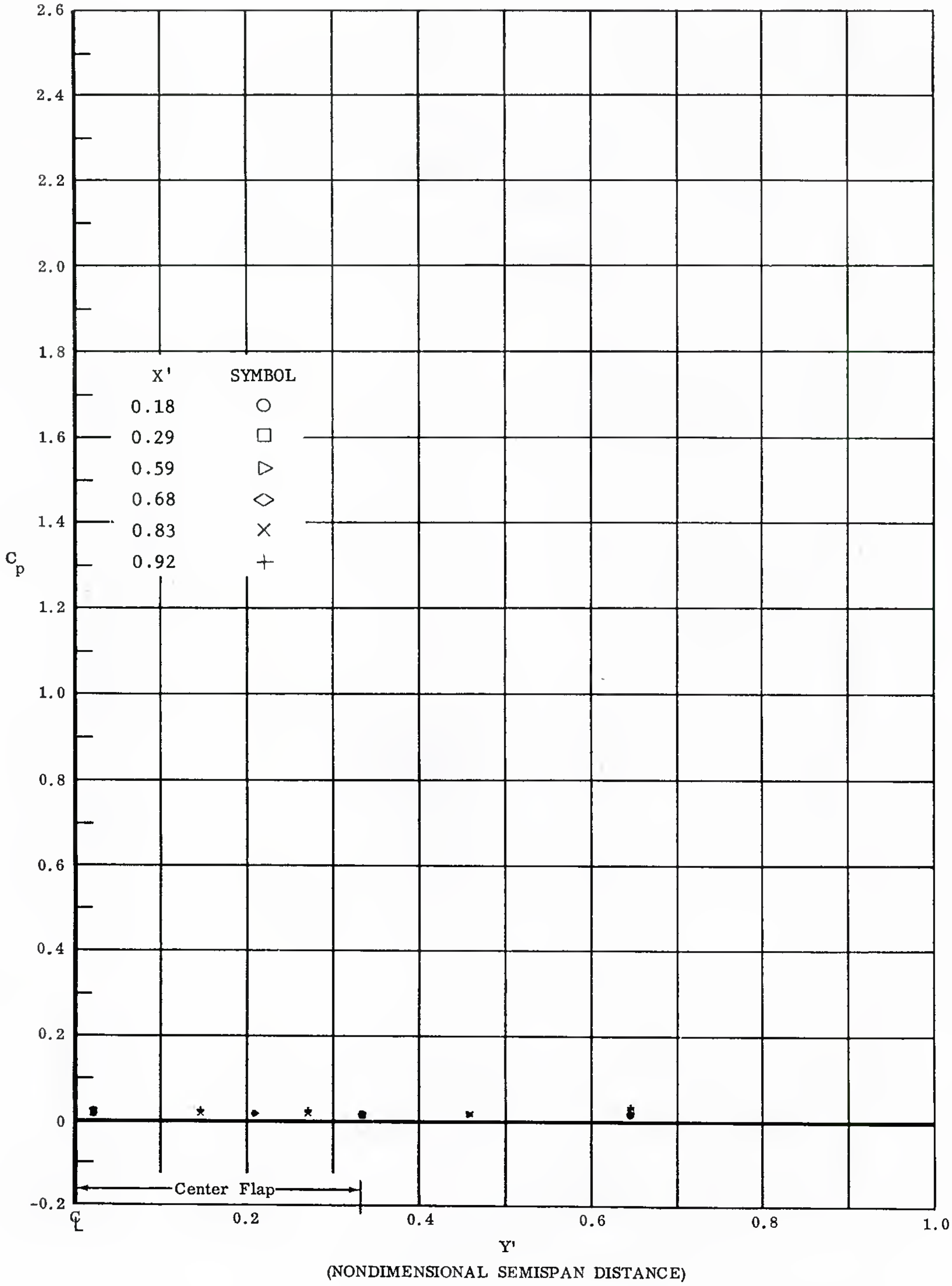


Fig. 50 Spanwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

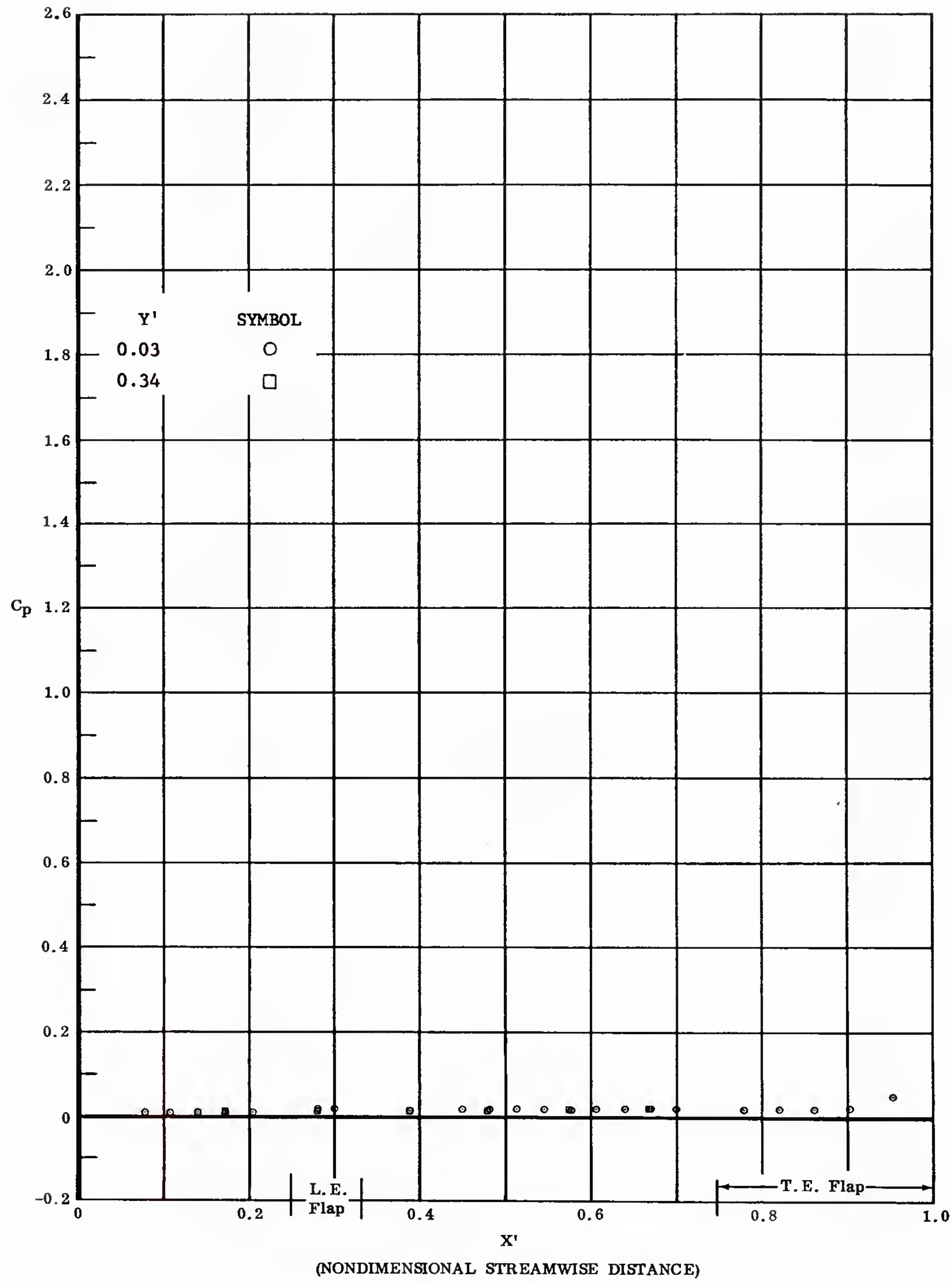


Fig. 51 Streamwise Pressure Distributions, End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

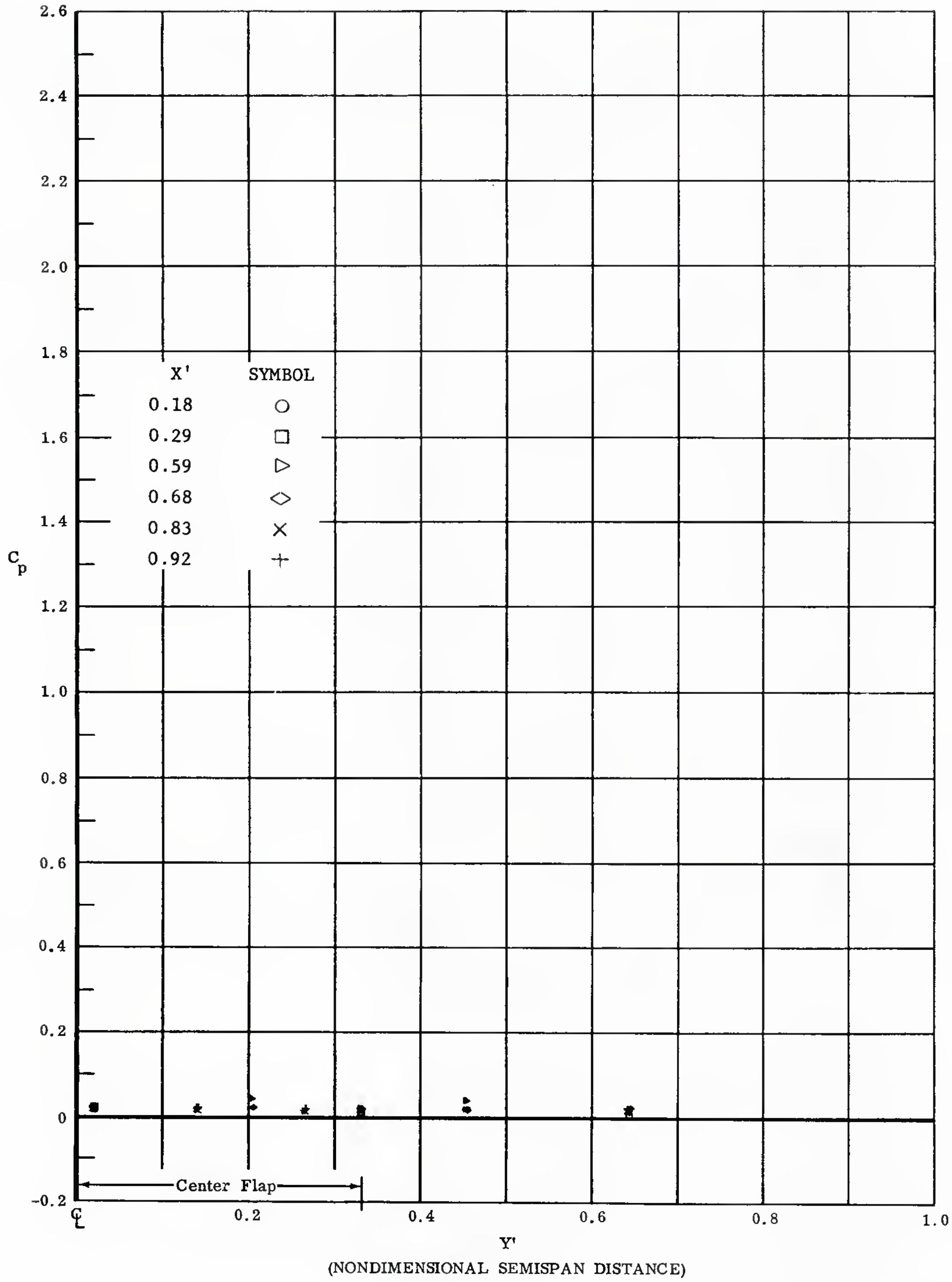


Fig. 51 Spanwise Pressure Distributions, End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = +5°$, $Re_\infty/ft = 3,300,000$

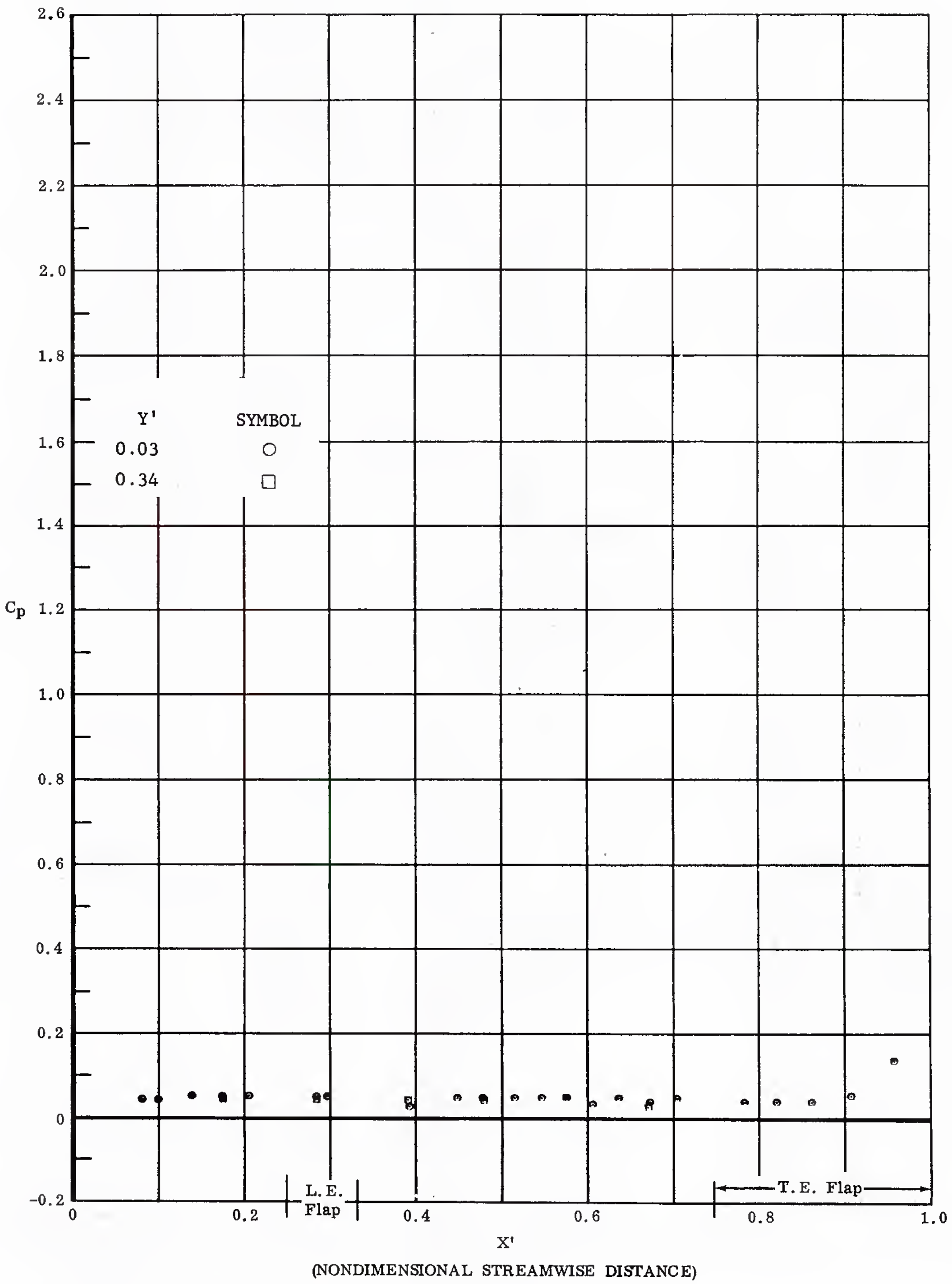


Fig. 52 Streamwise Pressure Distributions, End Plates On, Aft Full Span Flap Deflected 45°, α= +5°, Re_∞/ft = 3,300,000

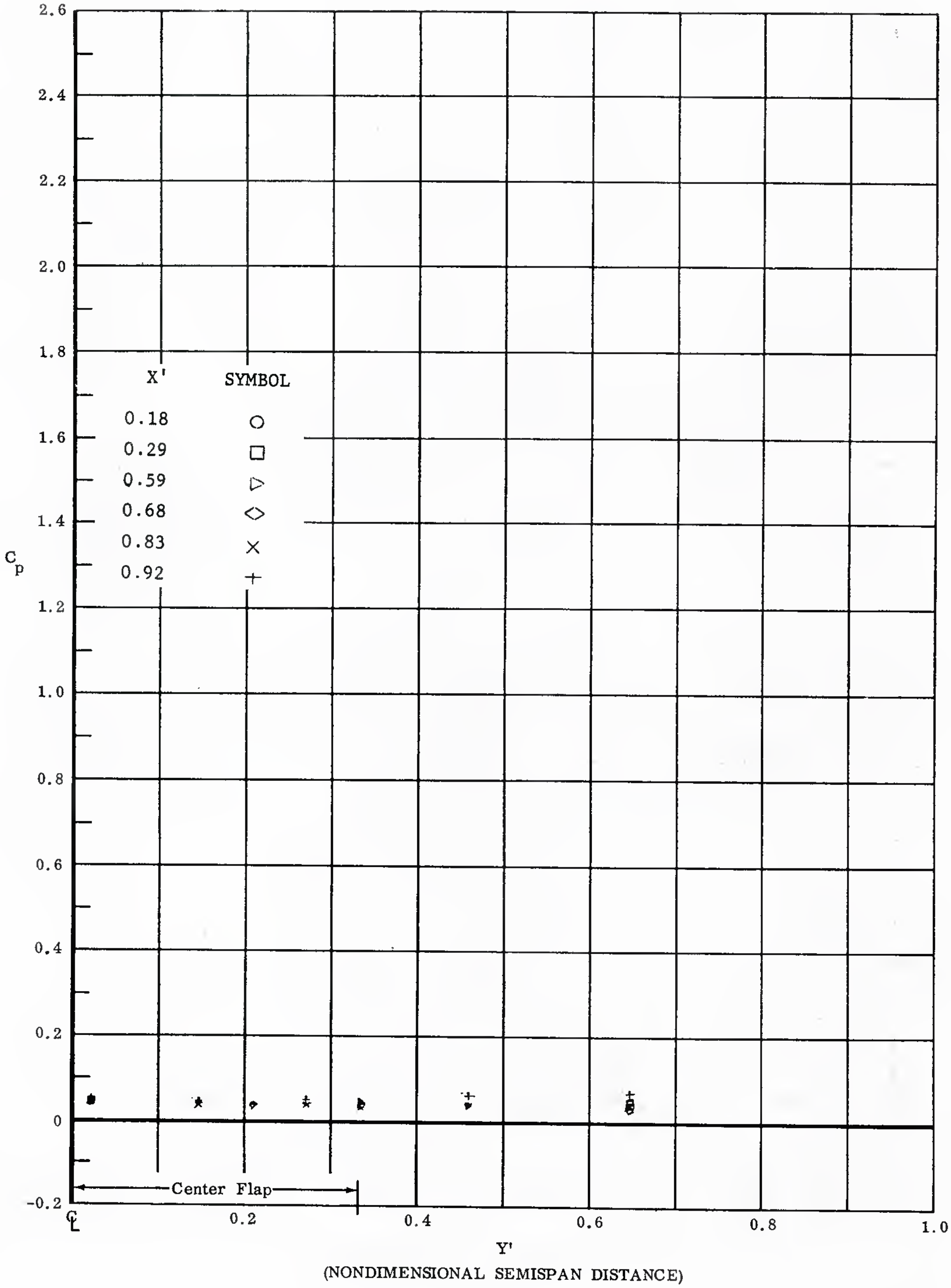


Fig. 52 Spanwise Pressure Distributions, End Plates On, Aft Full Span Flap Deflected 45°, α= +5°, Re_∞/ft = 3,300,000

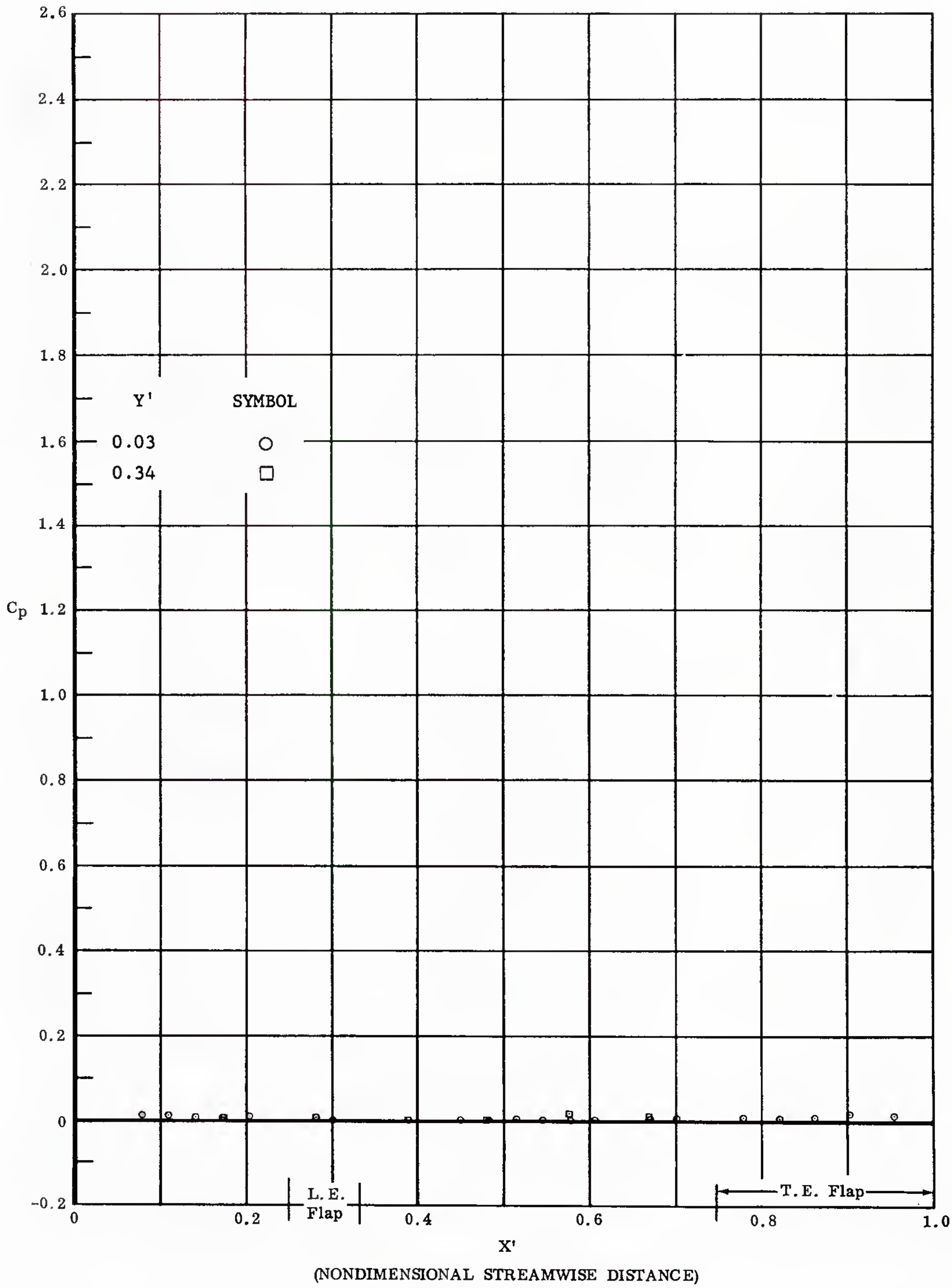


Fig. 53 Streamwise Pressure Distributions, End Plates On, No Flap Deflections, $\alpha = +15^{\circ}$, $Re_{\infty}/ft = 1,100,000$

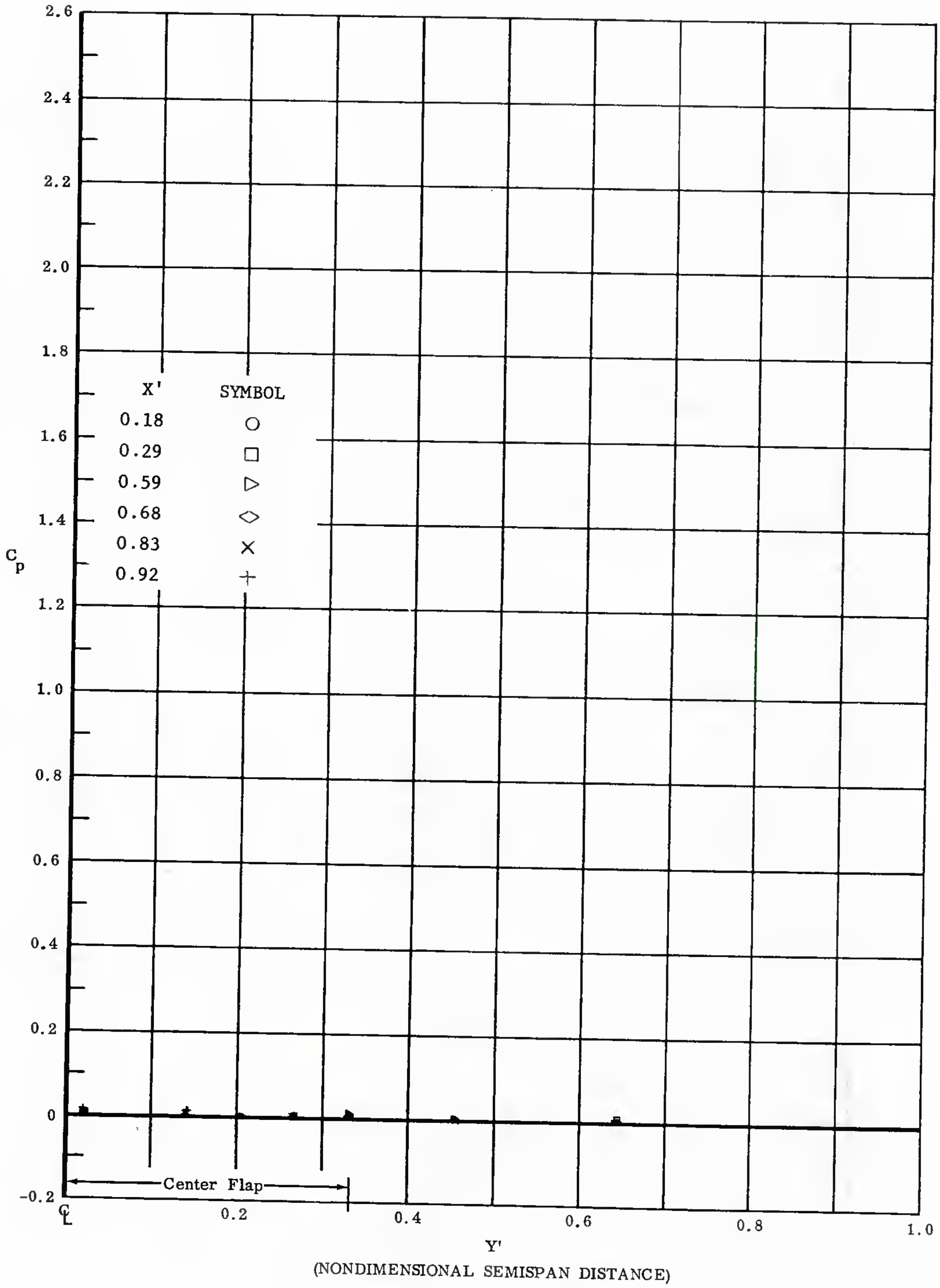


Fig. 53 Spanwise Pressure Distributions, End Plates On, No Flap Deflections, $\alpha = +15^{\circ}$, $Re_{\infty}/ft = 1{,}100{,}000$

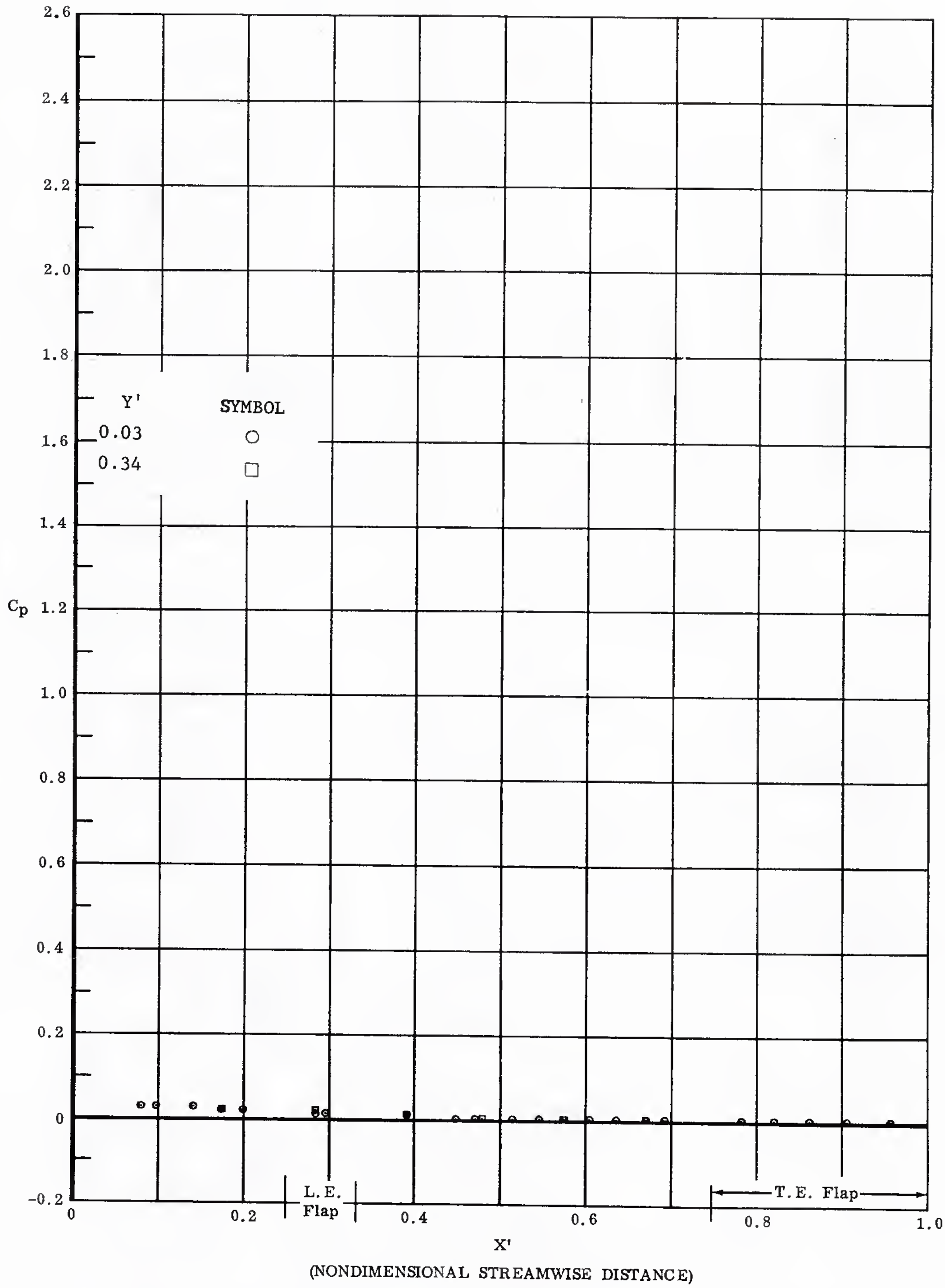


Fig. 54 Streamwise Pressure Distributions, End Plates Off, No Flap Deflections, $\alpha = +15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

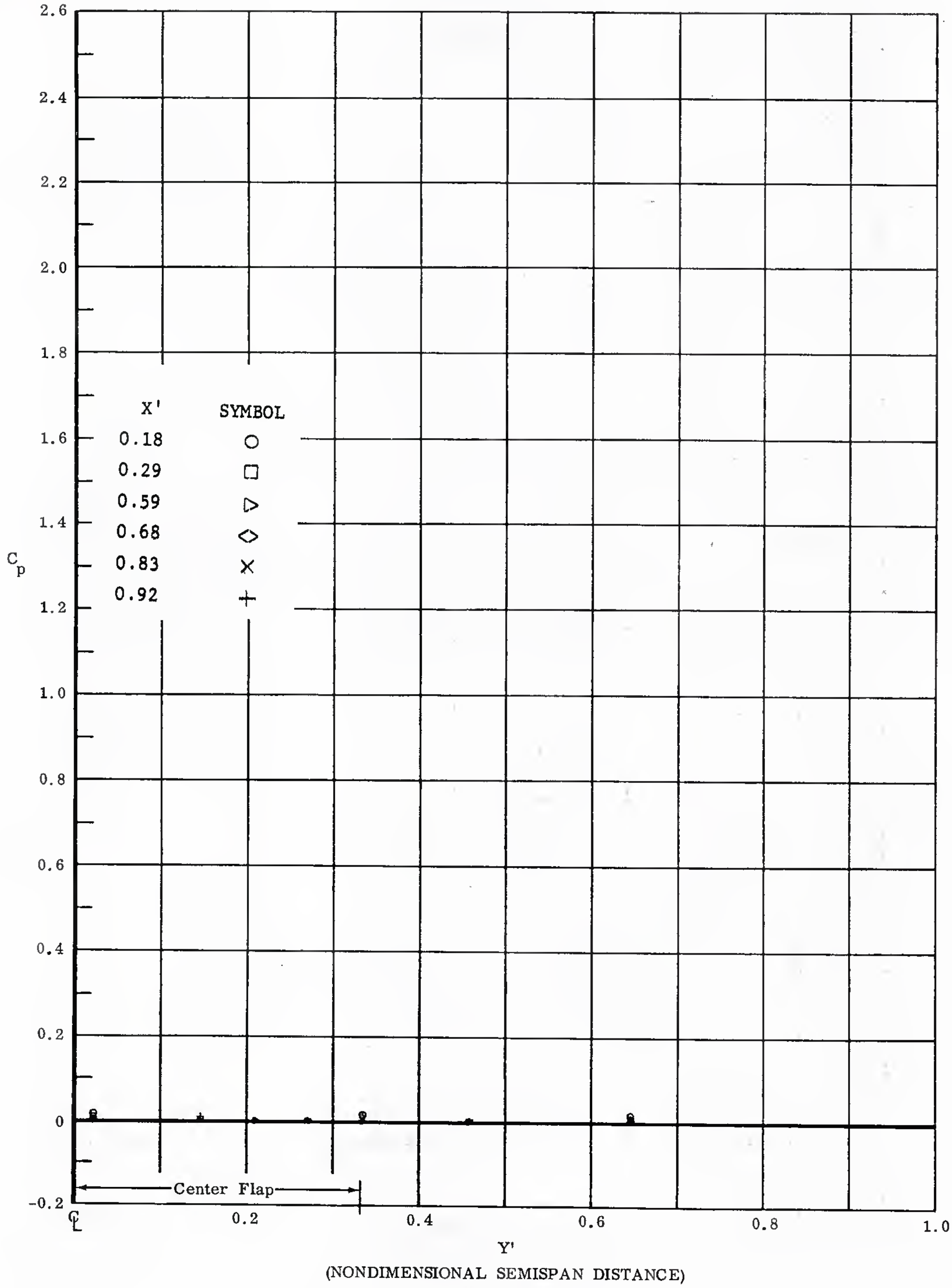


Fig. 54 Spanwise Pressure Distributions, End Plates Off, No Flap Deflections, $\alpha = +15^{\circ}$, $Re_{\infty}/ft = 3{,}300{,}000$

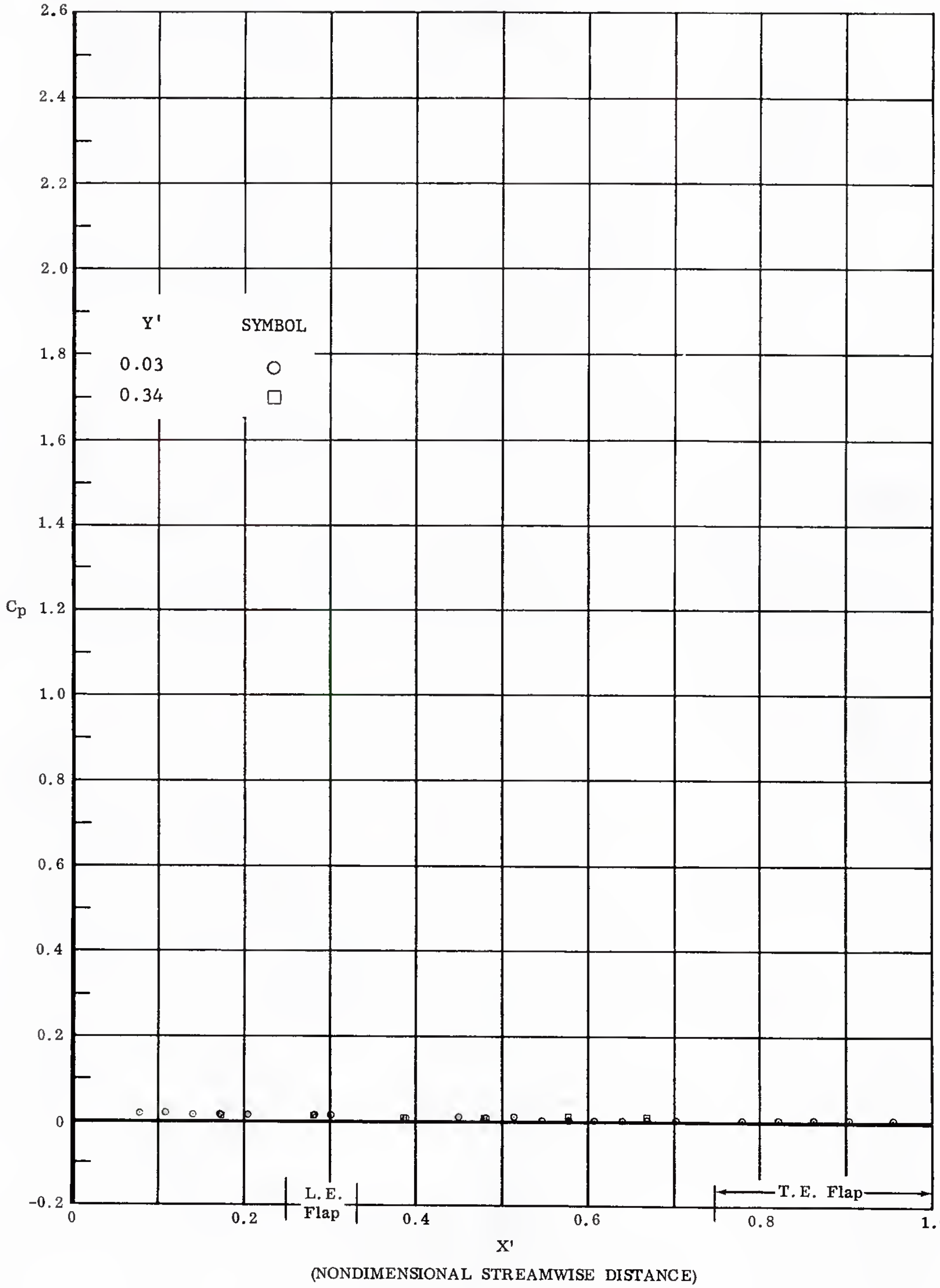


Fig. 55 Streamwise Pressure Distributions, End Plates On, No Flap Deflections, $\alpha = +15°$, $Re_\infty/ft = 3,300,000$

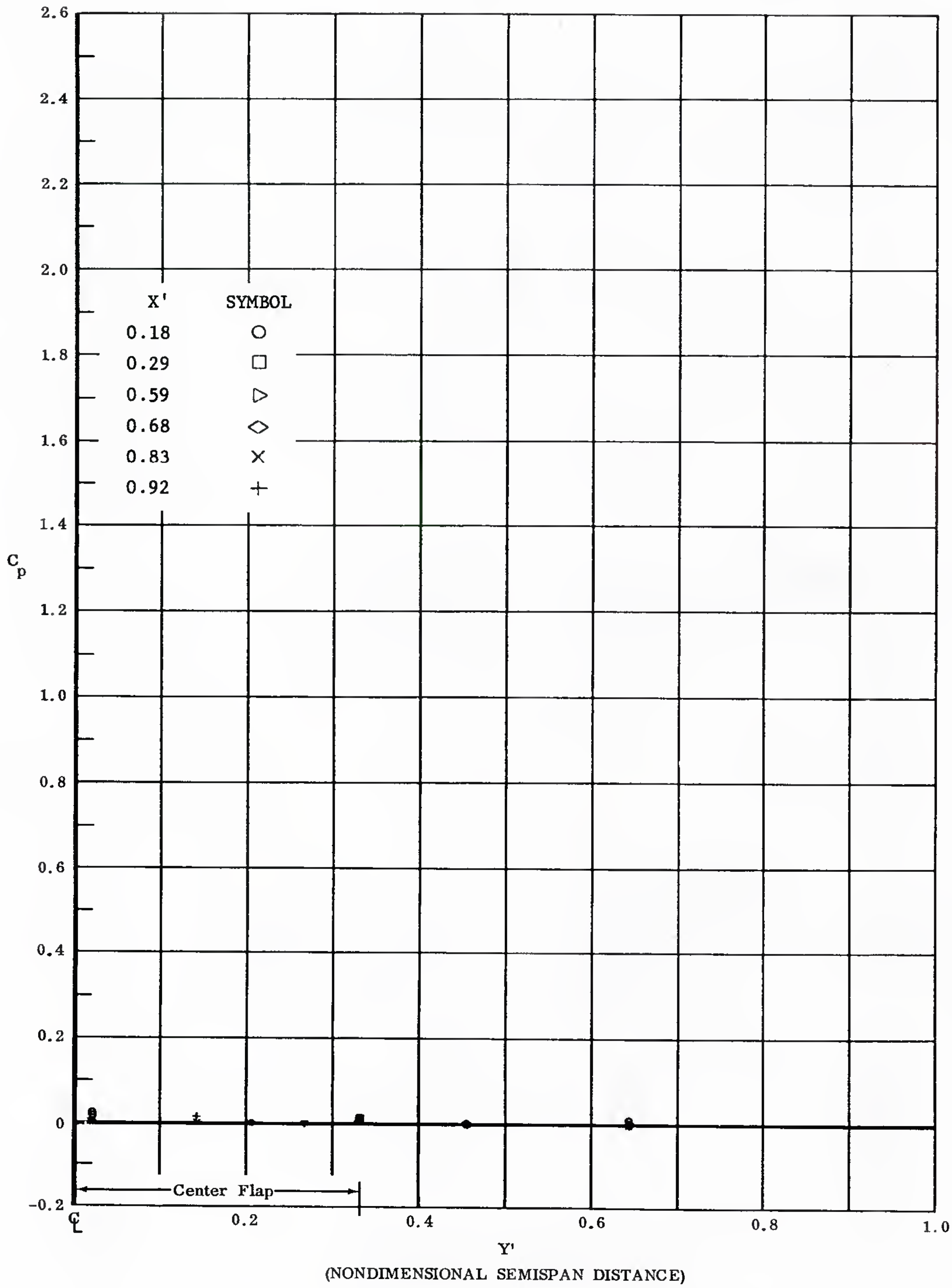


Fig. 55 Spanwise Pressure Distributions, End Plates On, No Flap Deflections, $\alpha = +15^{\circ}$, $Re_{\infty}/ft = 3,300,000$

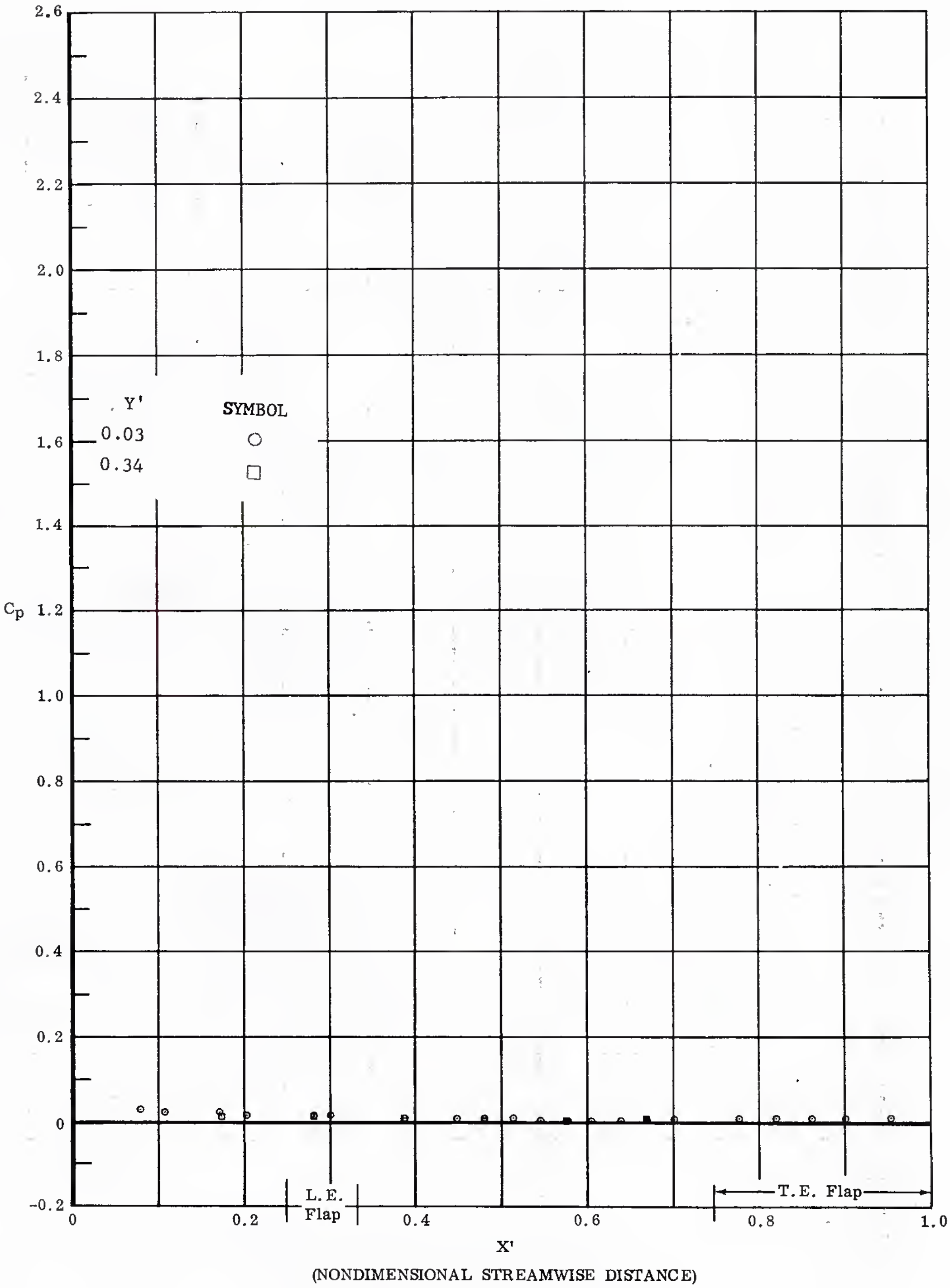


Fig. 56 Streamwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 10°, α = +15°, Re_∞/ft = 3,300,000

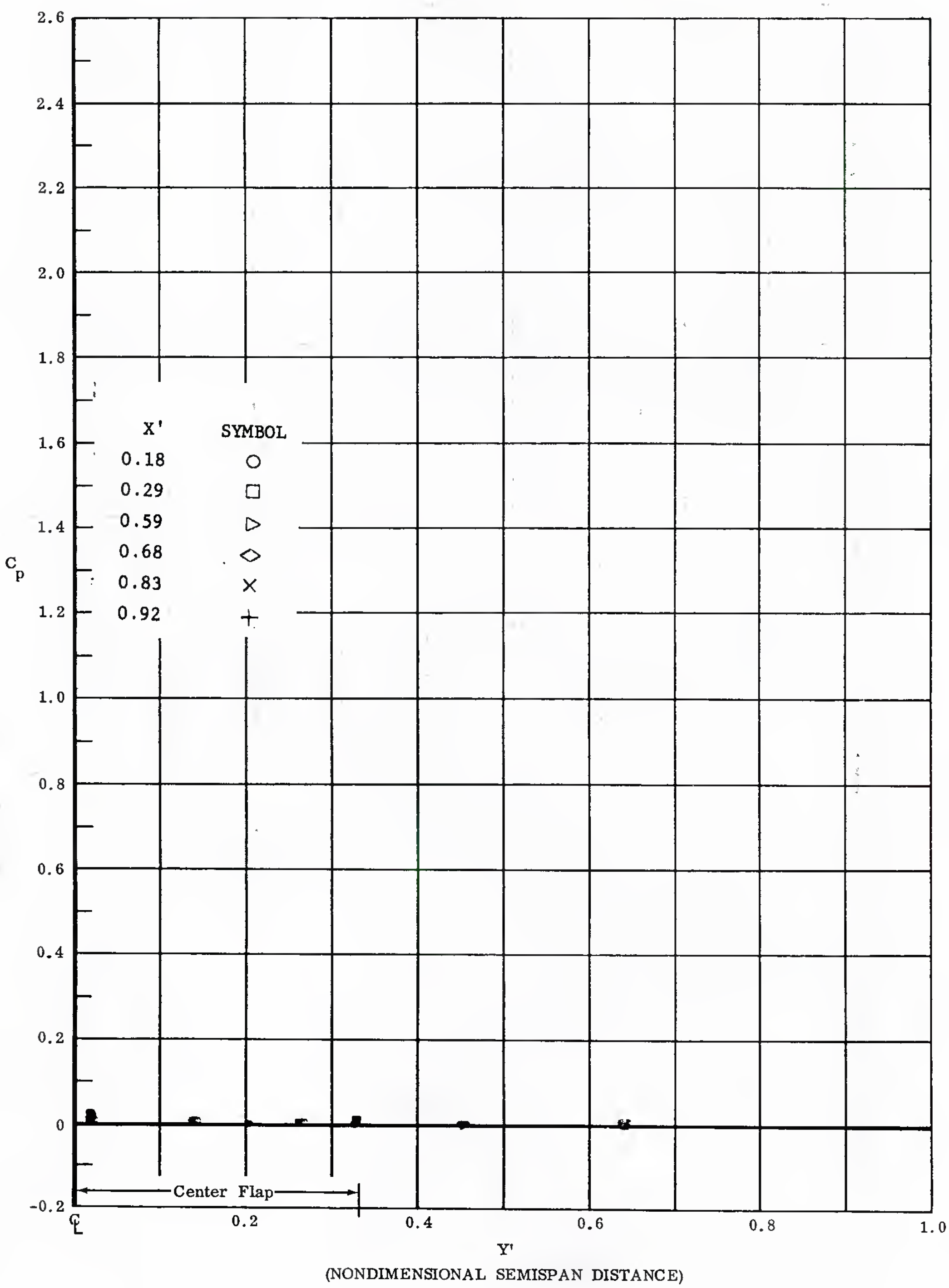


Fig. 56 Spanwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 10°, α = +15°, Re_∞/ft = 3,300,000

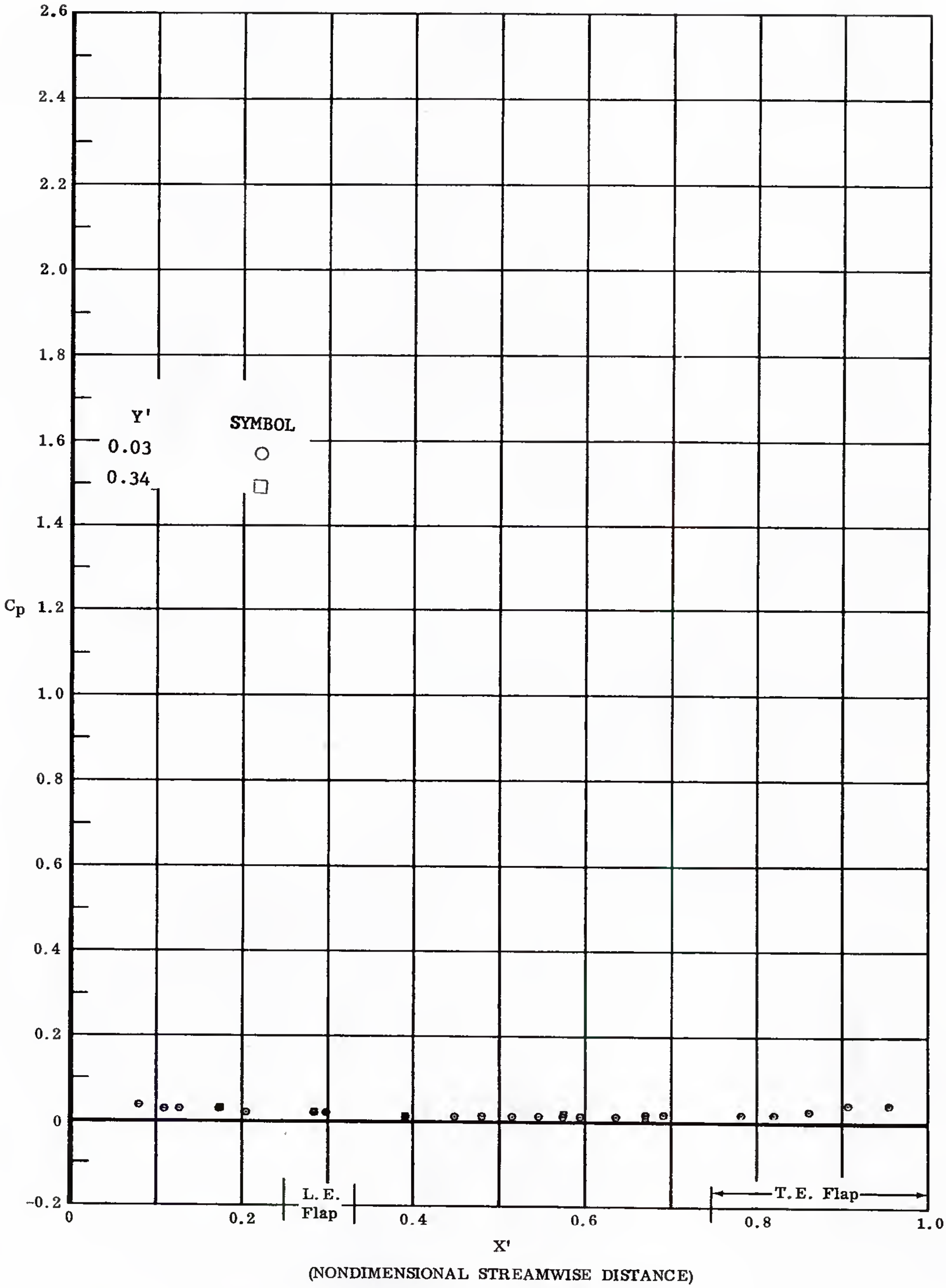


Fig. 57 Streamwise Pressure Distributions, End Plates Off, Aft Full Span Flap Deflected 20°, $\alpha = +15°$, $Re_{\infty}/ft = 3{,}300{,}000$

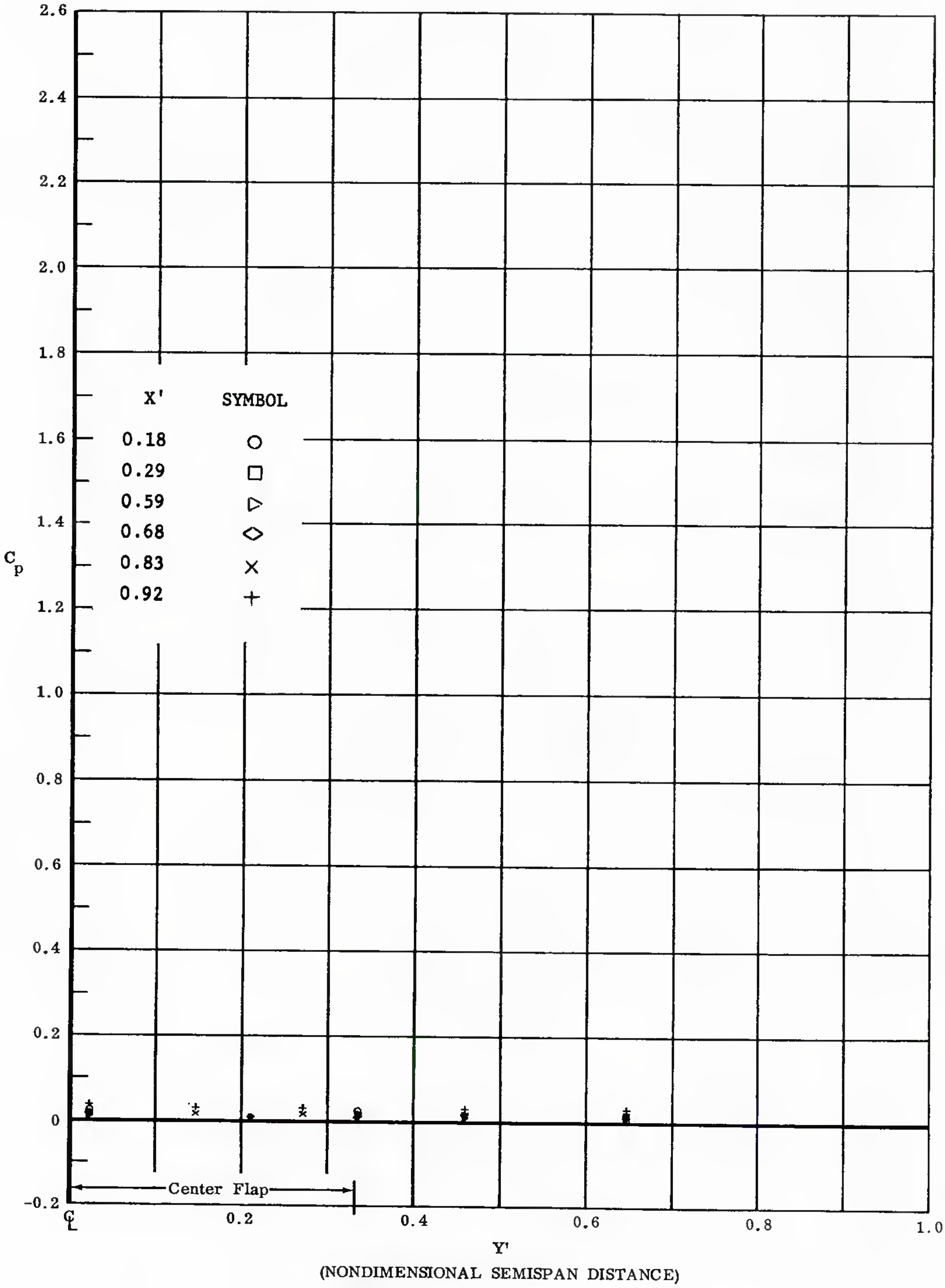


Fig. 57 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 20°, $\alpha = +15°$, Re_∞/ft = 3,300,000

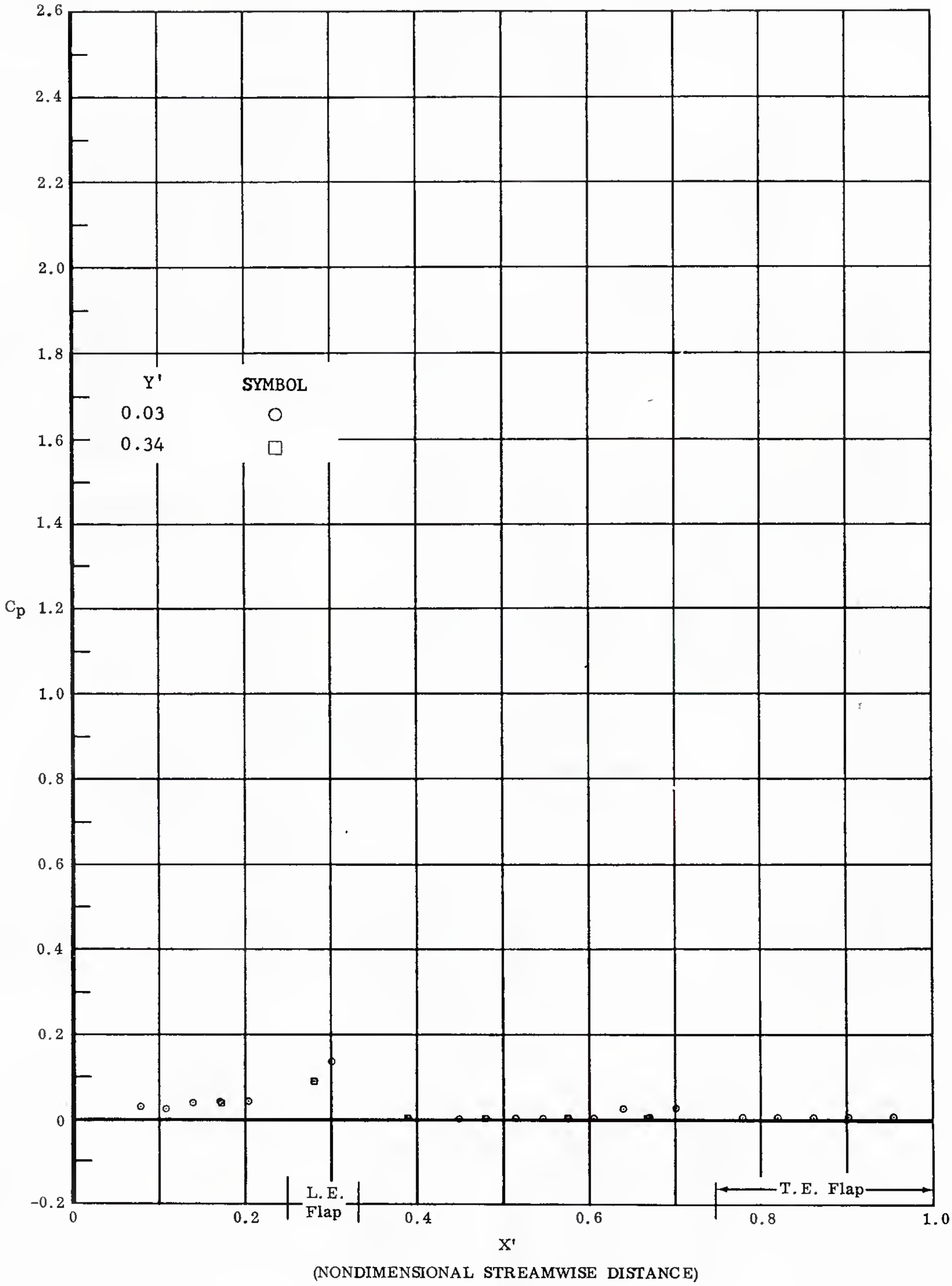


Fig. 58 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, α= +15°, Re_∞/ft = 3,300,000

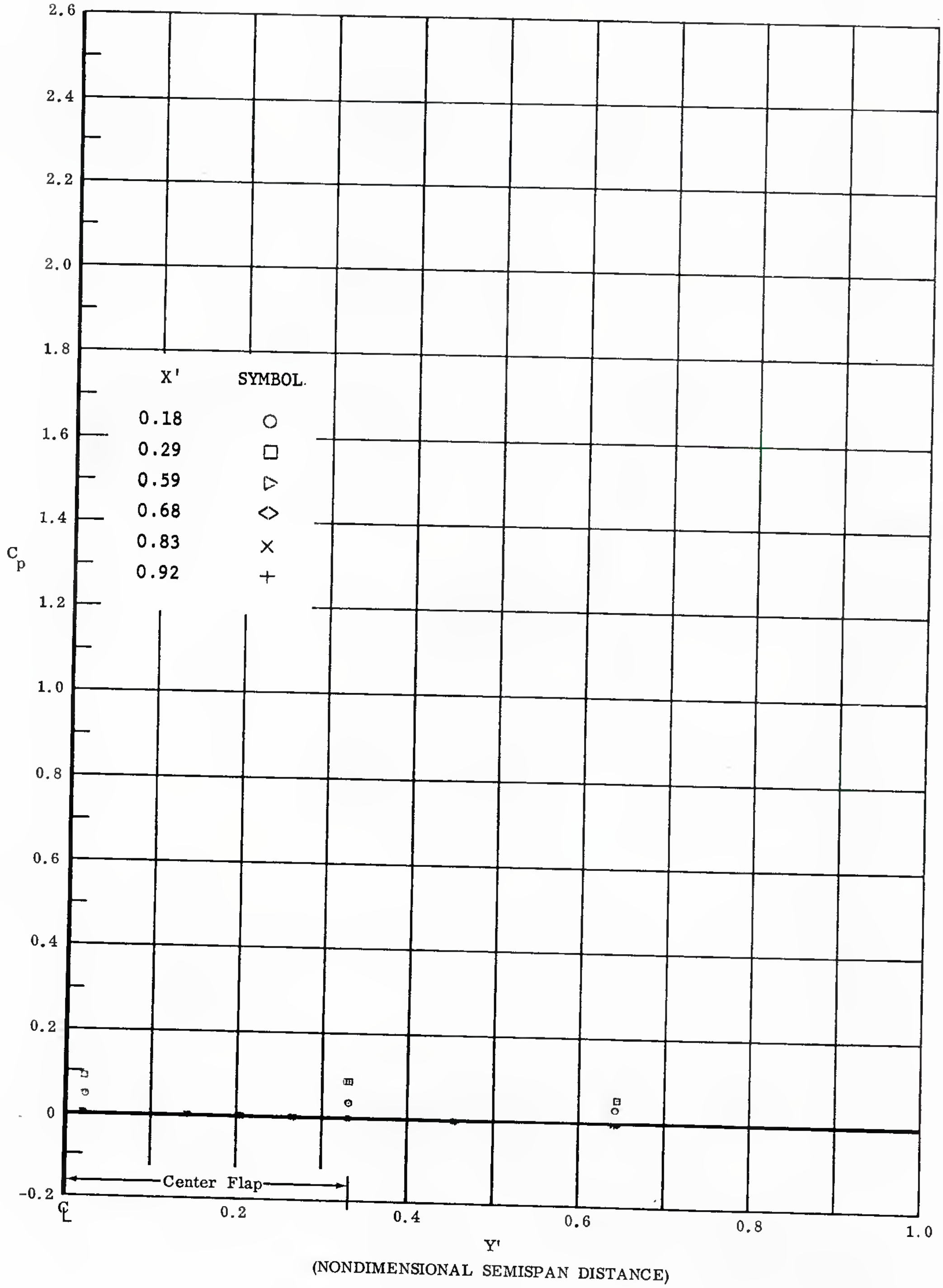


Fig. 58 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 30°, α = +15°, Re_∞/ft = 3,300,000

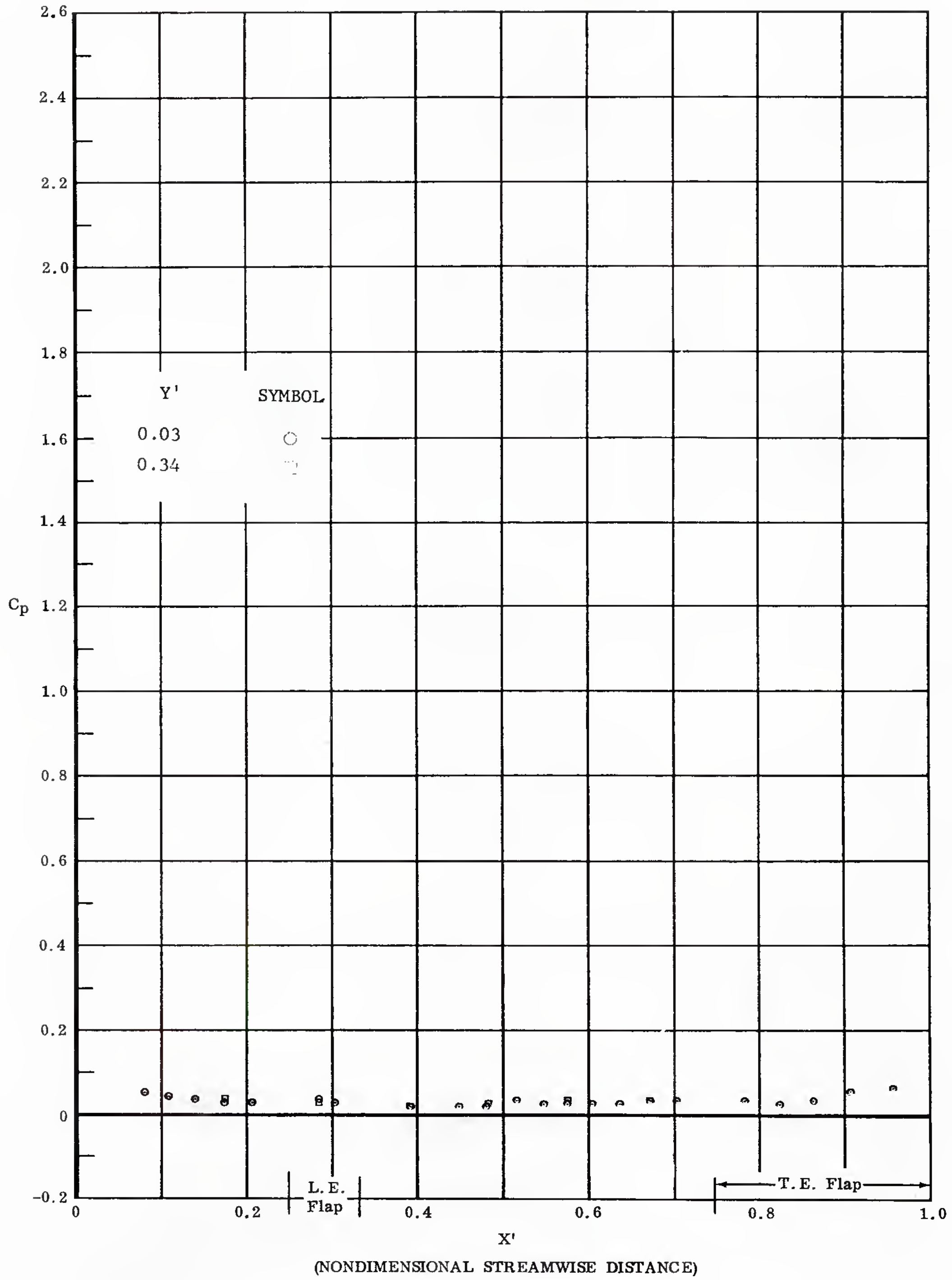


Fig. 59 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, α= +15°, Re_∞/ft = 1,100,000

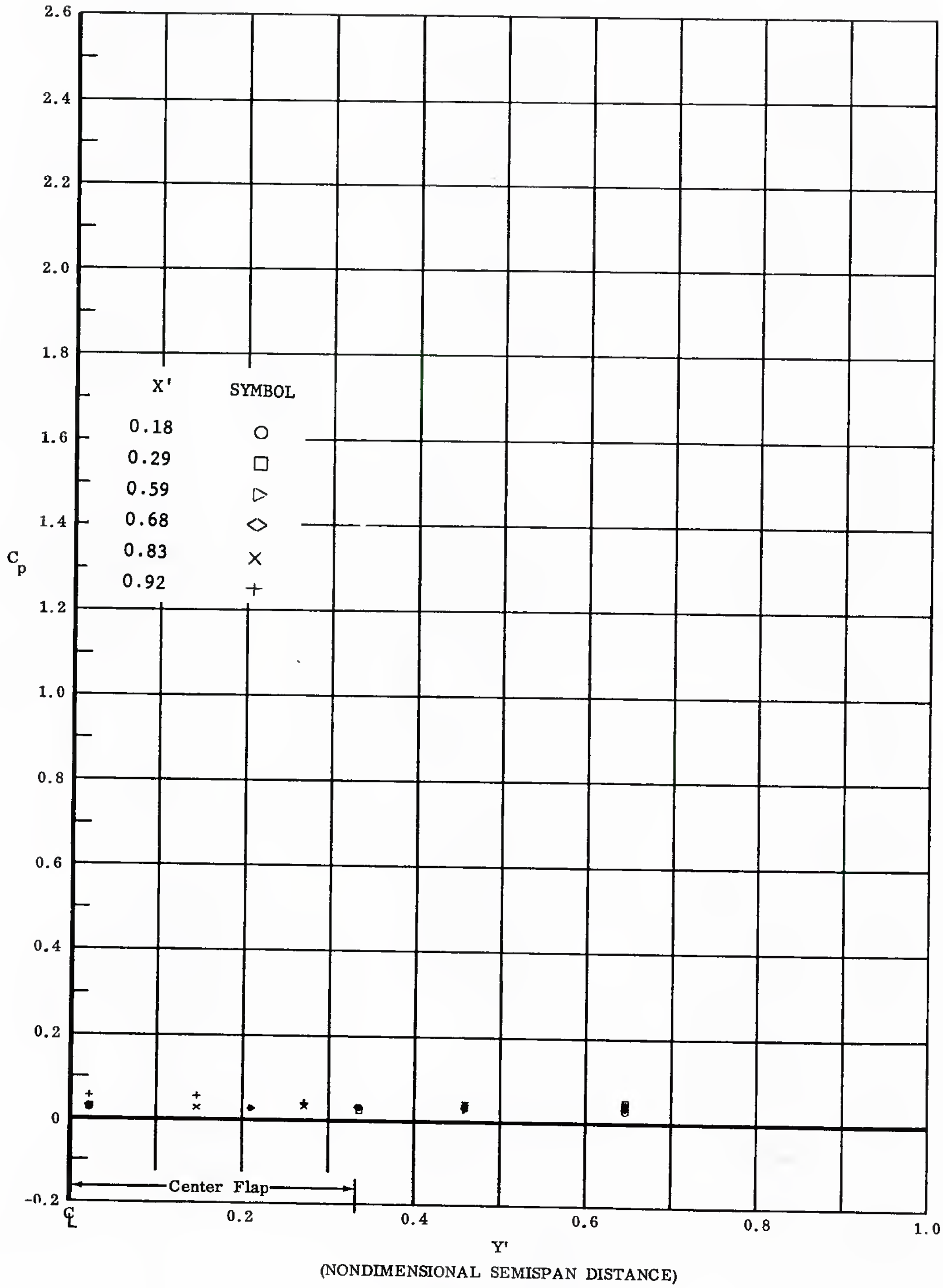


Fig. 59 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, α = +15°, Re_∞/ft = 1,100,000

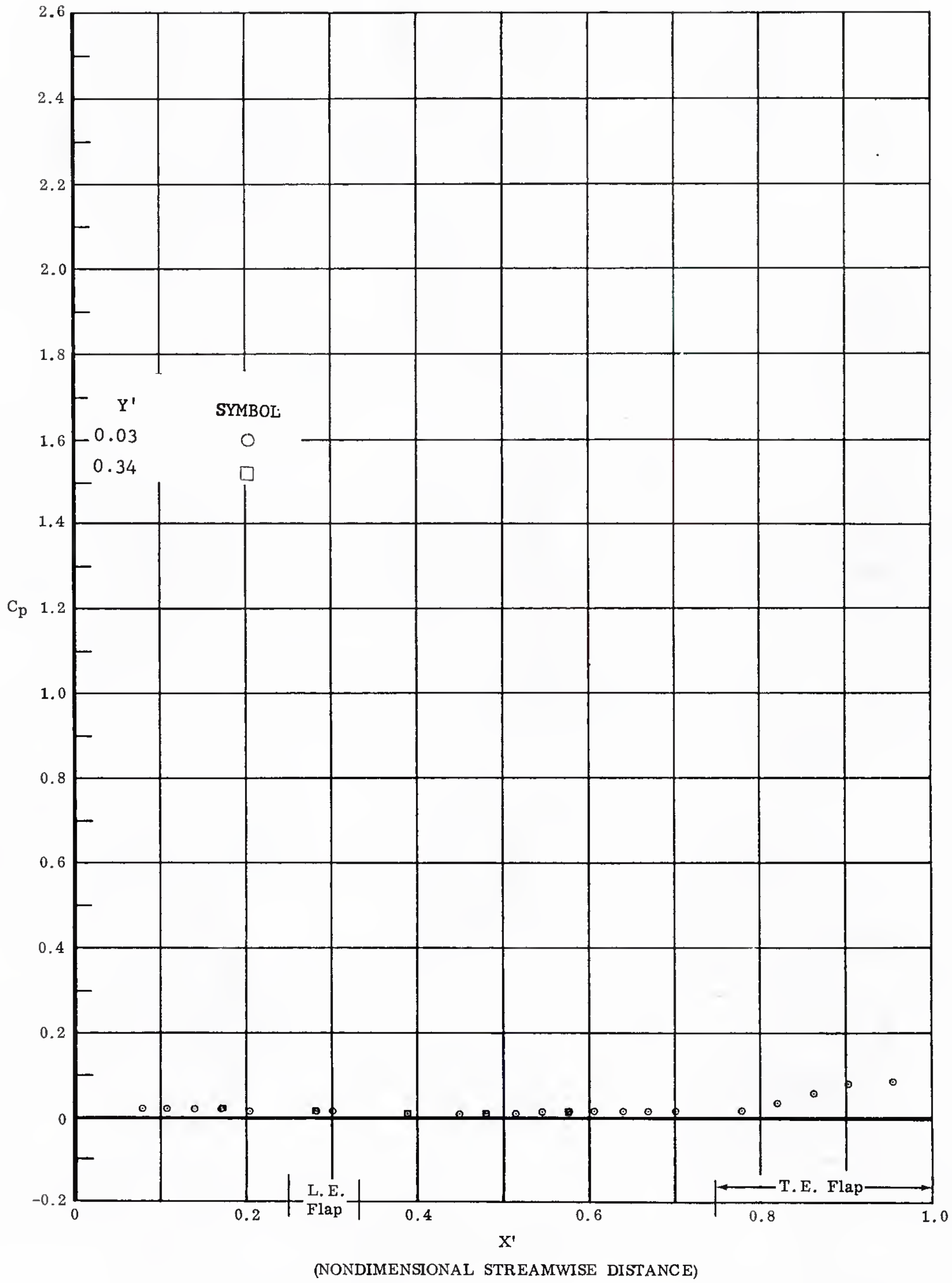


Fig. 60 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, α = +15°, Re_{∞}/ft = 3,300,000

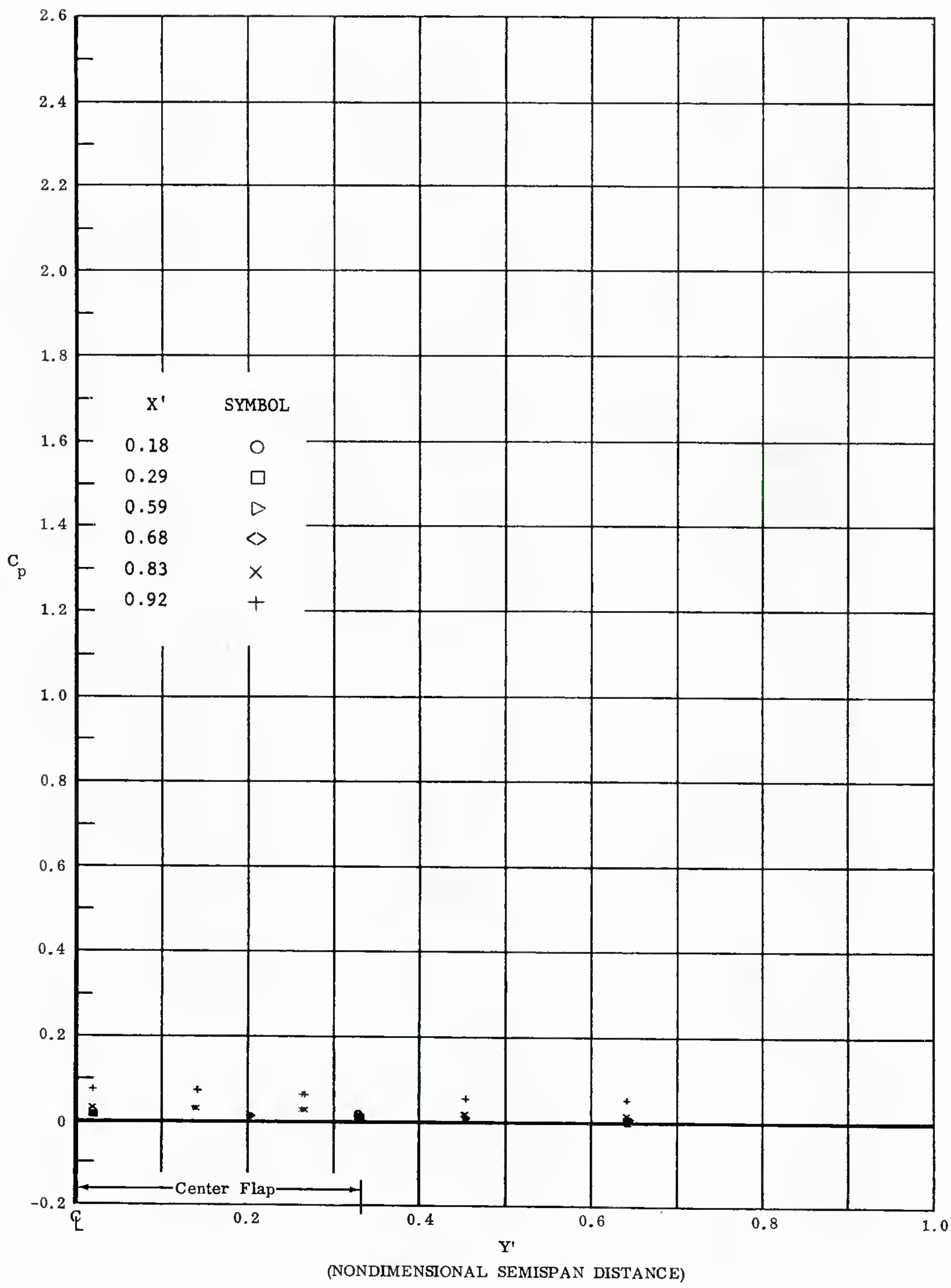


Fig. 60 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 30°, $\alpha = +15°$, $Re_\infty/ft = 3,300,000$

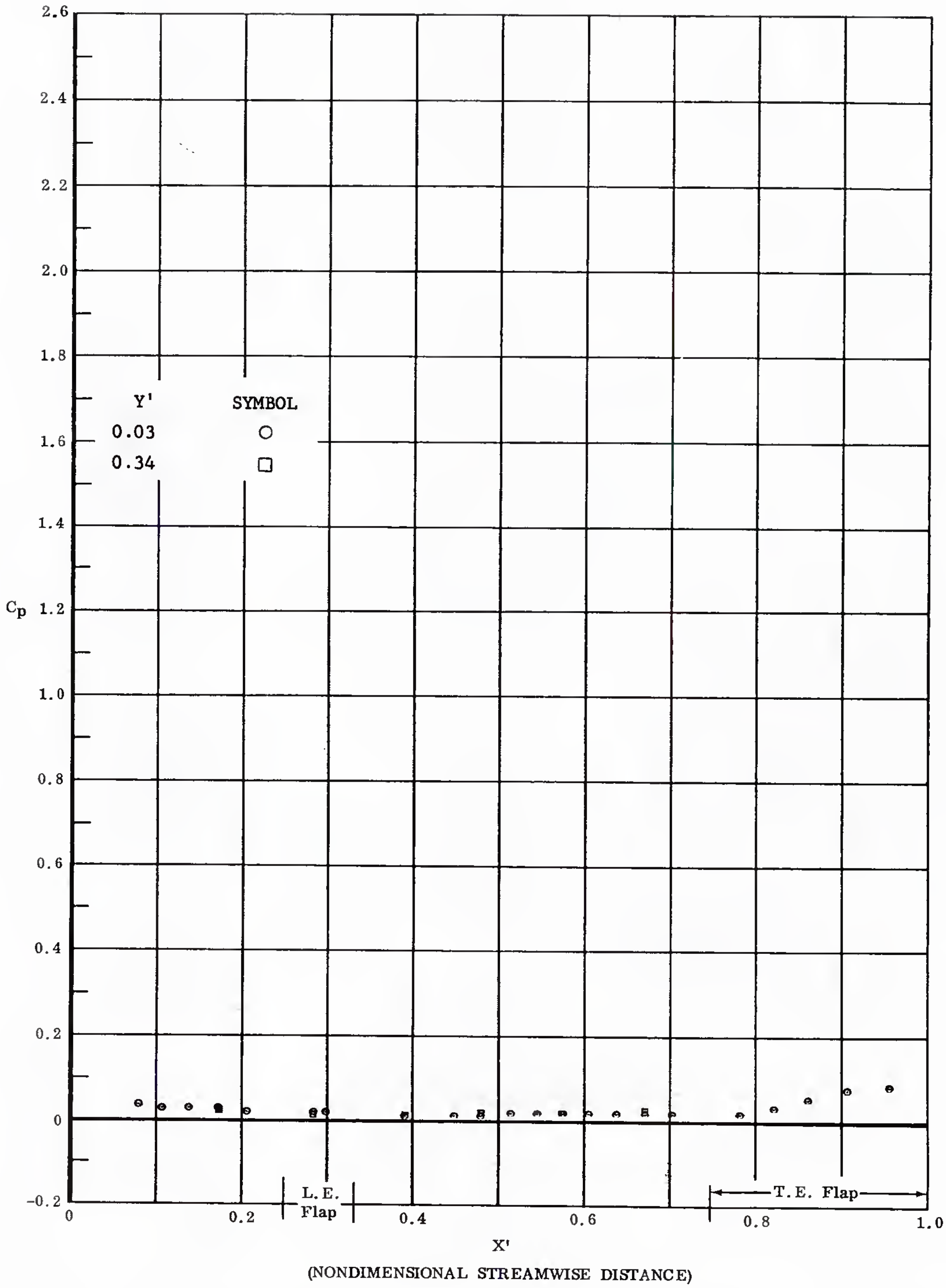


Fig. 61 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = +15°$, $Re_\infty/ft = 3{,}300{,}000$

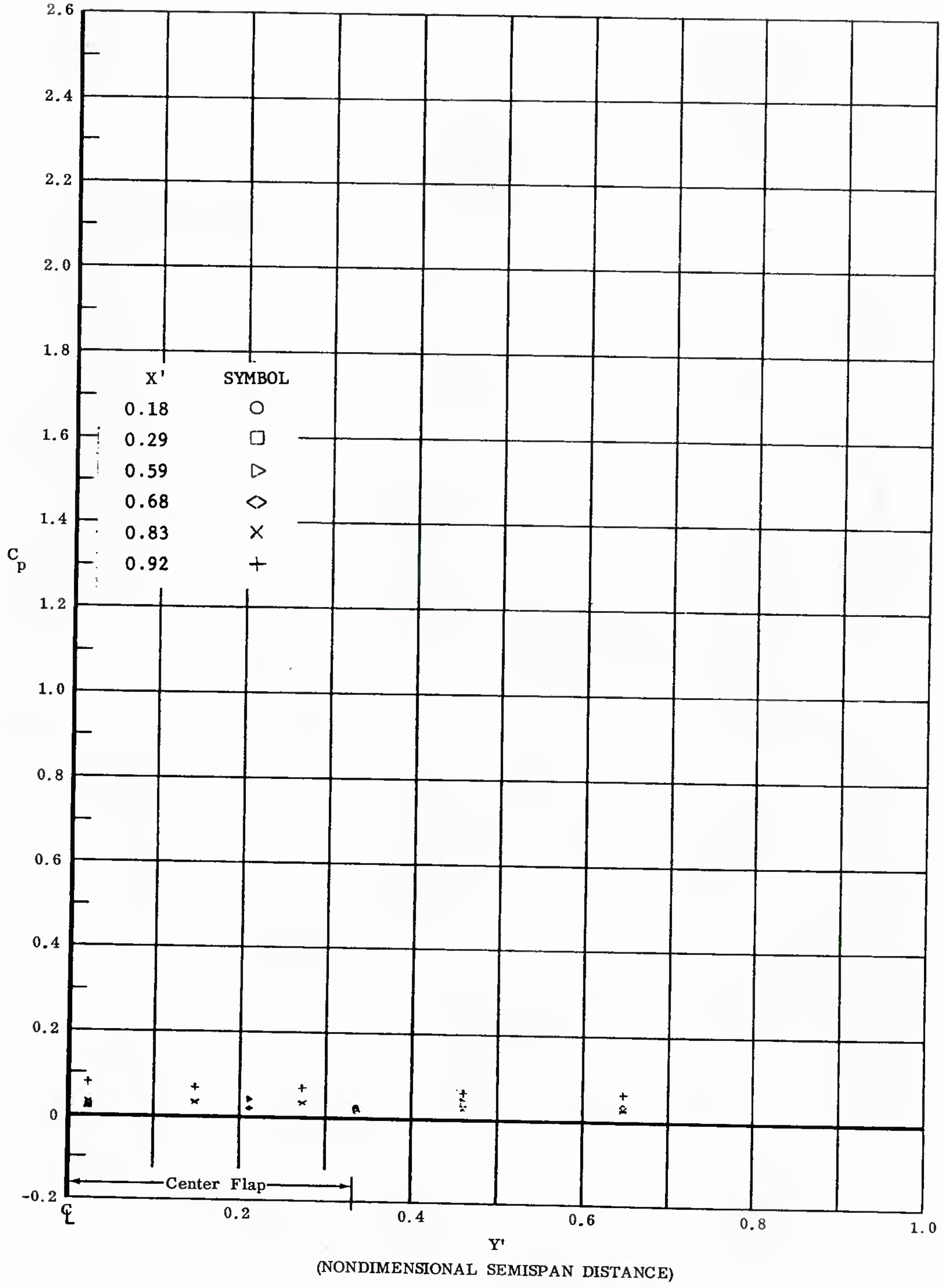


Fig. 61 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 30°, $\alpha = +15°$, $Re_\infty/ft = 3,300,000$

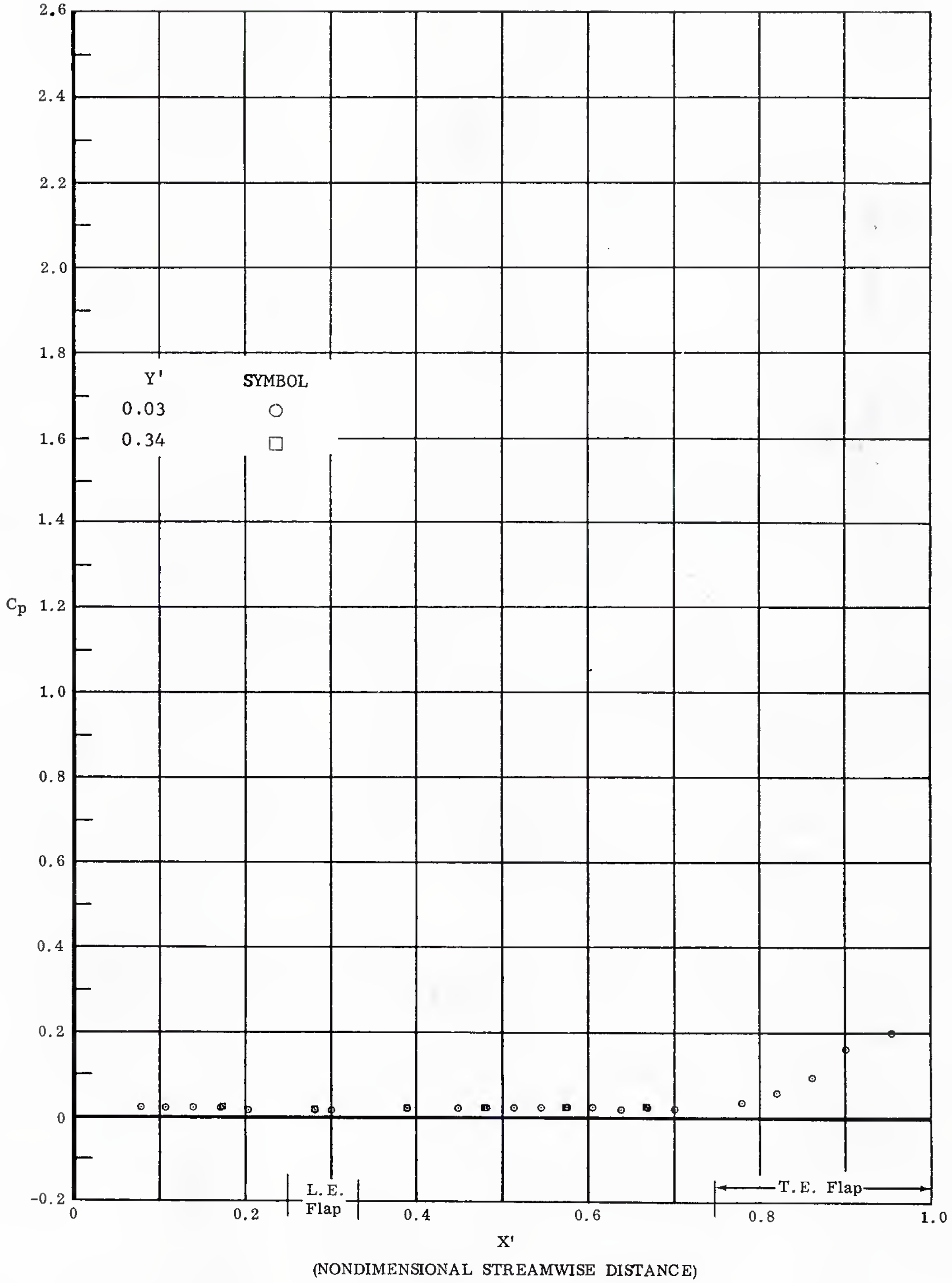


Fig. 62 Streamwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, α= +15°, Re_{∞}/ft = 3,300,000

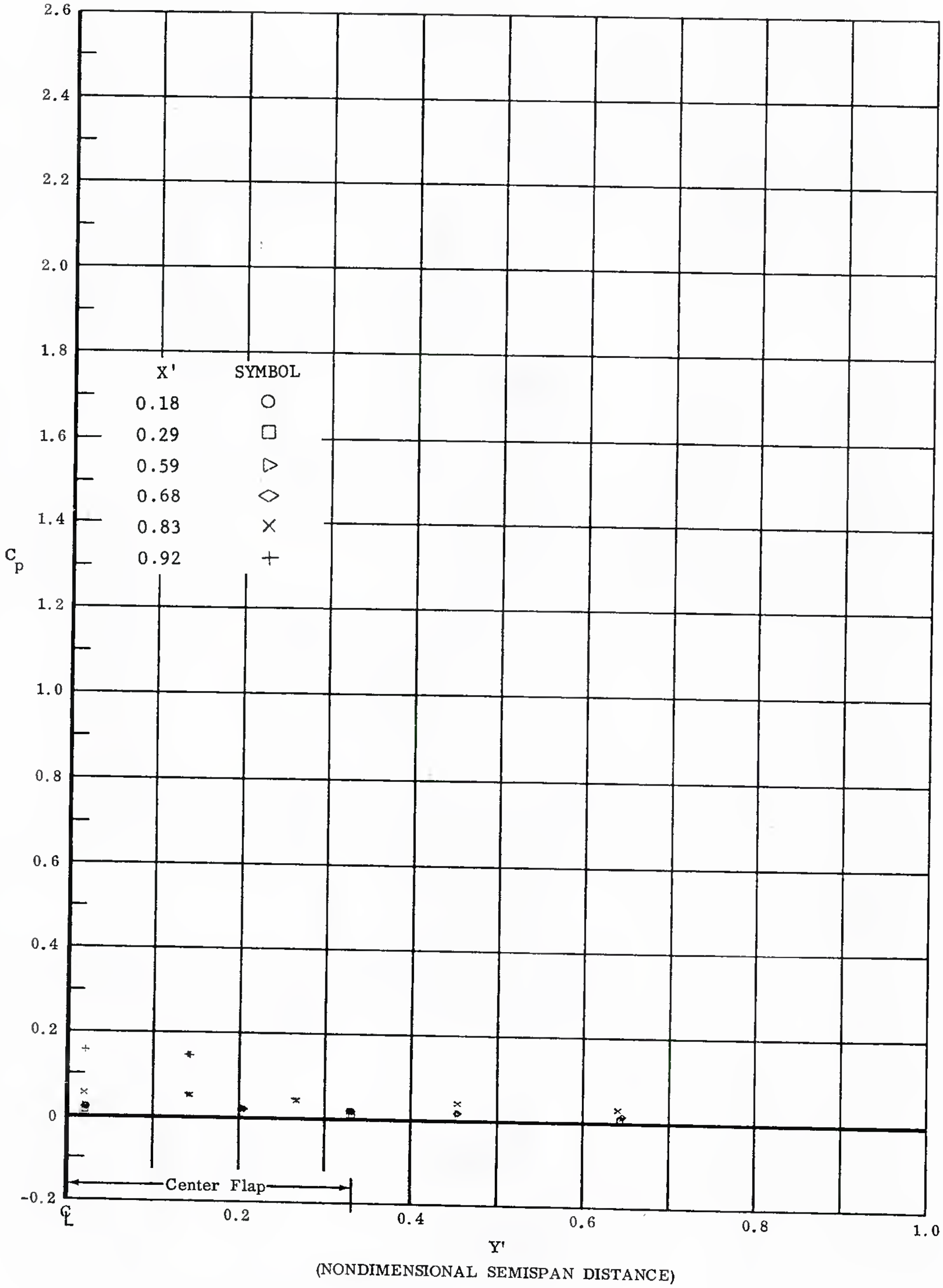


Fig. 62 Spanwise Pressure Distributions; End Plates Off, Aft Full Span Flap Deflected 45°, α= +15°, Re_∞/ft = 3,300,000

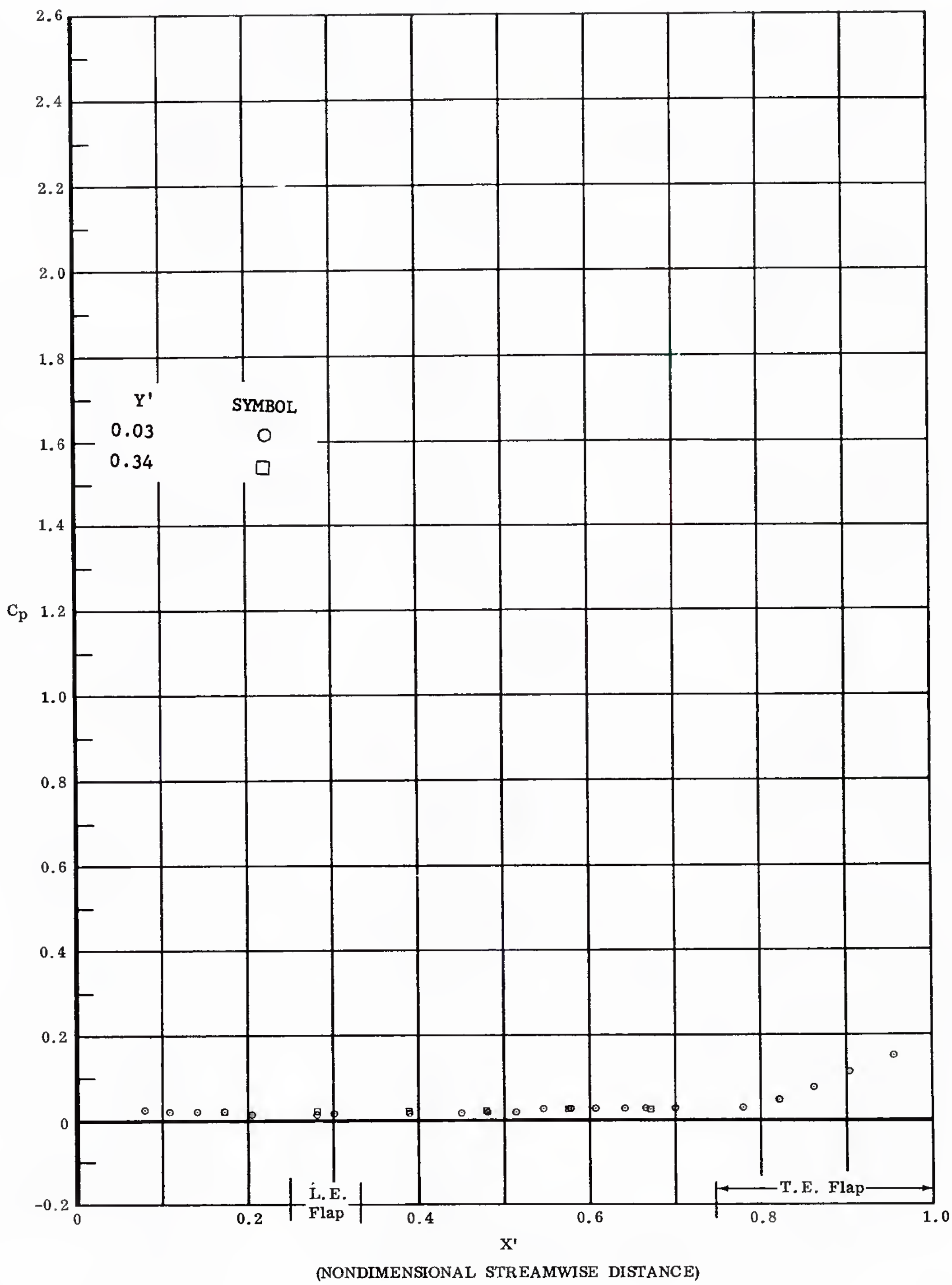


Fig. 63 Streamwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, α= +15°, Re_∞/ft = 3,300,000

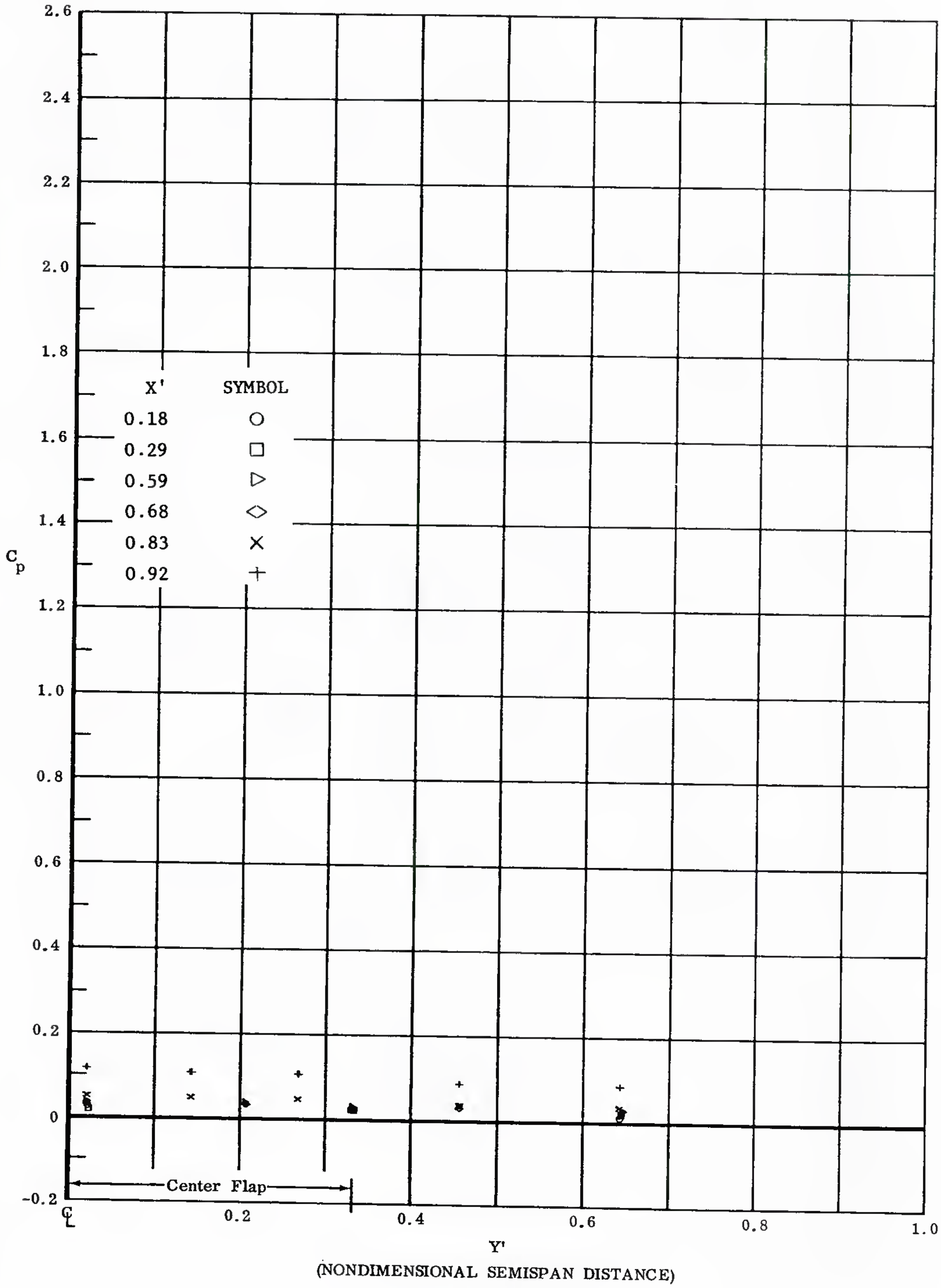


Fig. 63 Spanwise Pressure Distributions; End Plates On, Aft Full Span Flap Deflected 45°, α= +15°, Re_∞/ft = 3,300,000

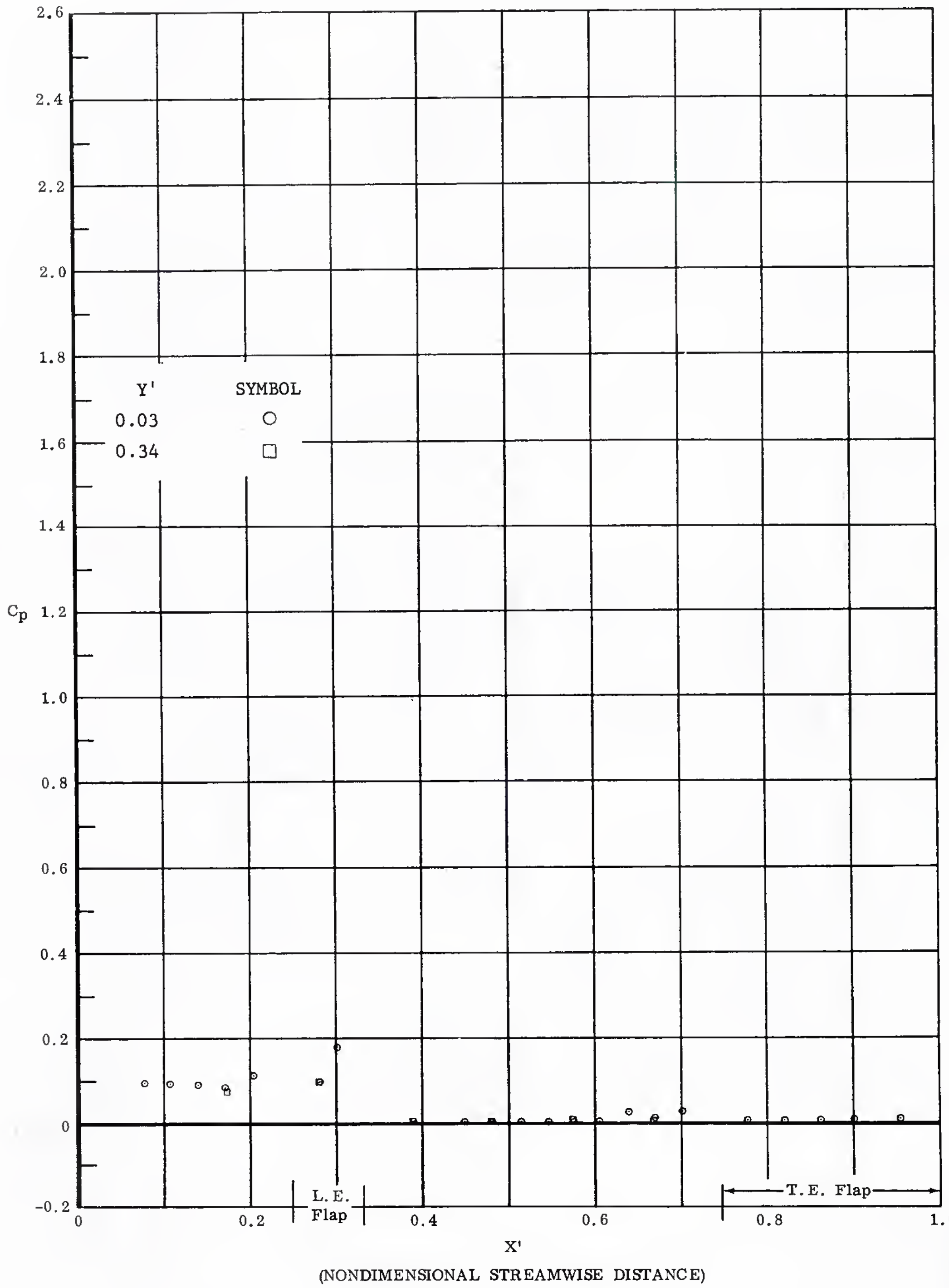


Fig. 64 Streamwise Pressure Distributions; End Plates Off, Forward Flap Deflected 90°, $\alpha = +15°$, $Re_{\infty}/ft = 3,300,000$

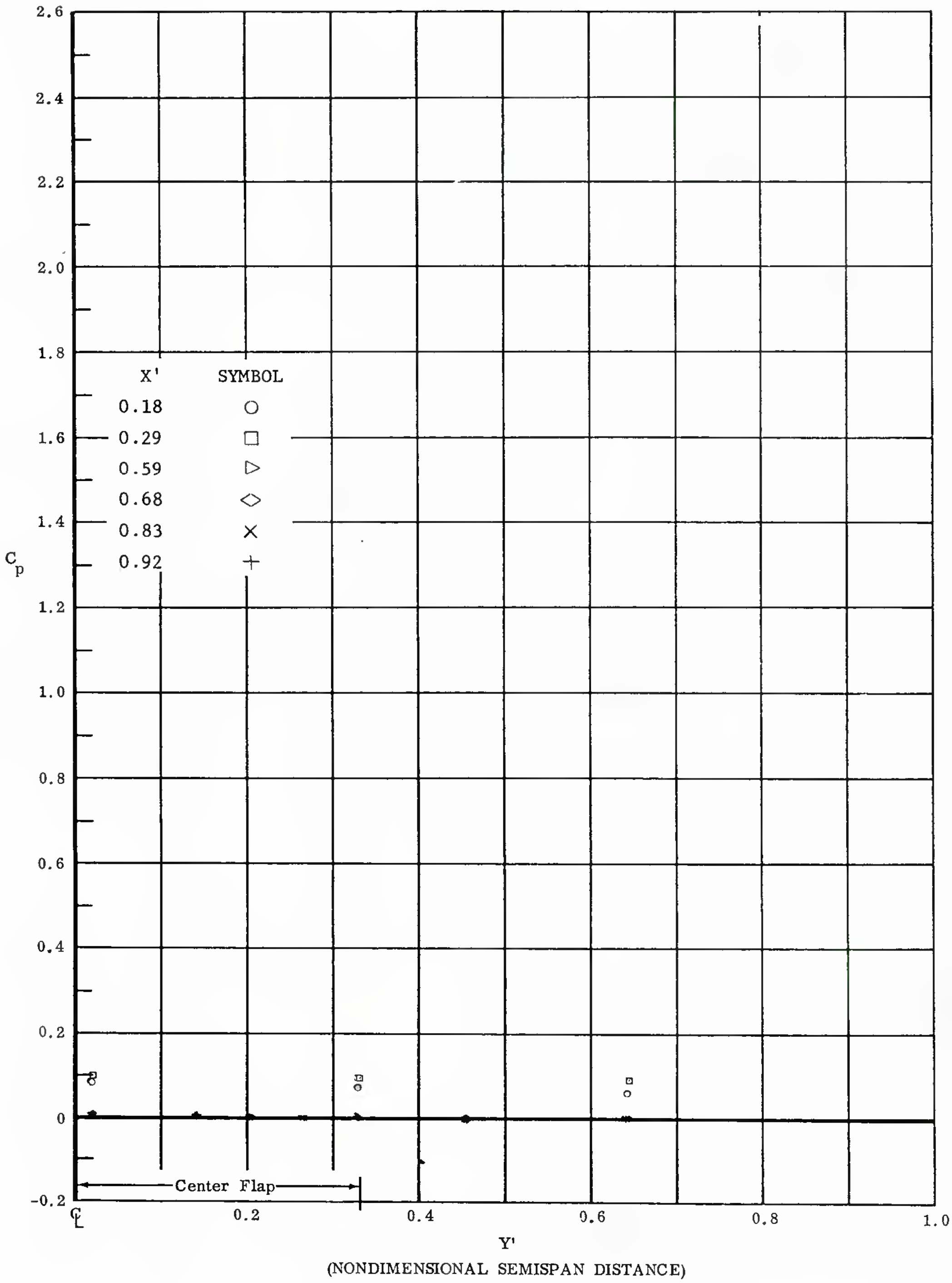


Fig. 64 Spanwise Pressure Distributions; End Plates Off, Forward Flap Deflected 90°, $\alpha = +15°$, $Re_\infty/ft = 3,300,000$